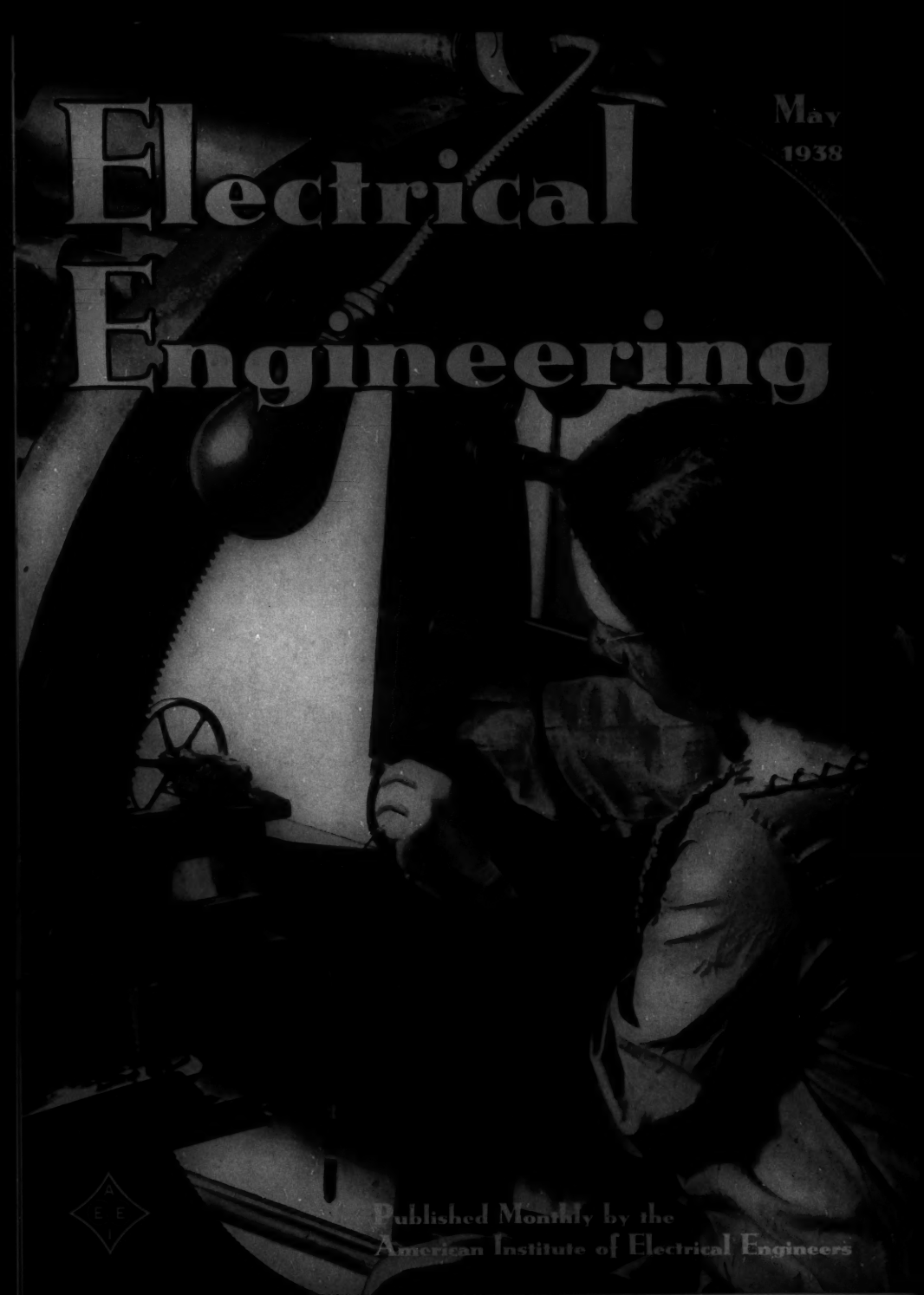
Electrical Engineering

May
1938



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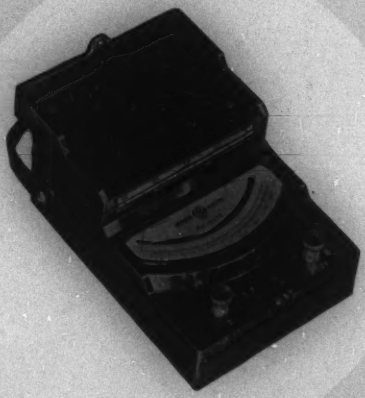

ONE AP-9 voltmeter, net price only $27, can form the basis for your testing set. With this single instrument you can begin to capitalize the many ways in which instruments may point the way to savings. It's a simple, inexpensive way to turn power losses into power savings.

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GENERAL ELECTRIC

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430-100

With the *VARIAC*...the *right* voltage every time

Thousands of enthusiastic users testify to the general utility of the VARIAC* *continuously adjustable* autotransformer for use in hundreds of different applications where exactly the right voltage is required on *any* a-c operated device.

The VARIAC is the original continuously-adjustable manual voltage control with these exclusive features found in no resistive type of control unit.

- **EXCELLENT REGULATION**—Output voltages are independent of load up to the full load rating of the VARIAC.
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- **CALIBRATED DIALS**—VARIACS are supplied with dials which read directly in output voltage or in output voltage as a percentage of line voltage.
- **SMALL TEMPERATURE RISE**—Less than 50 degrees C. for *continuous* duty.
- **ADVANCED MECHANICAL DESIGN**—Rugged construction—no delicate parts—two or more units may be ganged on the same shaft to control several circuits simultaneously.
- **SPECIAL UNITS**—For special applications requiring voltage adjustment over small ranges, with correspondingly increased output current, Types 70 and 80 VARIAC TRANSFORMERS can be supplied in quantity to your specifications.

VARIACS are stocked in fourteen models with power ratings from 170 watts to 2 kw; special units to meet the exact requirements of individual users may be obtained promptly and economically in quantity. Prices on the stock models range between $10.00 and $40.00.

** Trade name VARIAC is registered at U. S. Patent Office. VARIACS are patented under U. S. Patent 2009013 issued to General Radio Company.*

● *For Complete Details Write for Bulletin 266*

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Cambridge, Massachusetts

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MANUFACTURERS of RADIO and ELECTRICAL LABORATORY APPARATUS

"Holes you can

Ashton B. Taylor, President, Burlington Electric Motor Service, Inc., Winooski, Vt.

Reduces power losses $100 a month

Sample of the savings that may be expected when electrical circuits are modernized is found in the experience of a creamery in Shelburne, Vermont, circuits of which were overhauled by Burlington Electric Motor Service, Inc. In a letter to Mr. Taylor, president of Burlington, the creamery manager writes: "As a result of overhauling our electric motors and rewiring only a few of our power circuits, we have had not alone uninterrupted service from our motors, but through the excellent workmanship and quality of materials used, *our power losses have been reduced to a point where we save approximately $100 a month.* We are satisfied, when all our circuits have been rewired, that our saving will be proportionately greater."

USE MODERN IMPROVED

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ANACONDA WIRE & CABLE CO., General Offices: 25 Broadway, New York
Subsidiary of Anaconda Copper Mining Company

put your fist through!"

You fix the leaks you see—but what of invisible leaks —electrical leaks? They are wasting dollars constantly. They mostly come from old-fashioned wiring.

DEFICIENT WIRING costs industrial plants thousands of dollars. Estimates show that in *nine out of 10 plants, important savings could be made by bringing antiquated, outworn circuits up-to-date!*

Energy waste is not easy to detect. Overloads cause serious heat losses. Power "evaporates" invisibly. Maintenance and repair bills are higher than they should be. Even more important are losses caused by machinery breakdowns. Men stand around idle. Products spoil in process. Dollars fly out the window every hour until repairs are completed.

Factories are not the only places where electric energy is being wasted needlessly. New electrical equipment often puts a heavy overload on commercial building circuits. Greater use of copper in the form of modern, improved cables would save money every month in the year.

A check-up costs nothing

Do something today to guard against these dangers. Have a check-up of electrical circuits made. It may save you many dollars. The two books shown at the right give complete instructions for making a study of your plant's wiring. Your electrical engineer, industrial consultant, or your electrical contractor can do the work.

If you have a specific problem in mind, consult our Engineering Department. We will cooperate without obligation. It will pay you to learn about the many improvements in cable design engineered by Anaconda.

A non-metallic sheathed duct cable now becoming popular for industrial applications

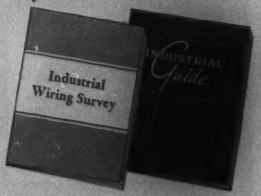
ANW was originally designed for underground low voltage secondary network service. Millions of feet are giving perfect service in that capacity. So satisfactory is its record, that engineers are selecting it for industrial, commercial and mining applications. In locations under the jurisdiction of the National Electric Code, Underwriters' Laboratories have approved the use of ANW *without lead sheath covering* for application in moist locations where heretofore only lead sheathed cables were approved.

Characteristics of ANW are: 1. Resistance to moisture; heat and flame; solvent action of oils, alkalies; deterioration due to oxidation and heat. 2. Ease of handling even under varying climatic conditions.

Write for booklet No. C-39

These books tell how to end "headaches" caused by antiquated electric circuits.

The "Industrial Wiring Survey" tells how to make a check-up of electric circuits. The "Industrial Guide for the Selection of Wire & Cable" tells how to correct conditions found. Both books are free. 38483



& Cable

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FIFTY YEARS OF 1888 1938 INSTRUMENT LEADERSHIP

TODAY

Weston is 50 years young!

THIS month, the Weston Electrical Instrument Corporation begins its second half-century of leadership in electrical measurement. Naturally, it is an occasion justifying legitimate pride and self-satisfaction.

Yet, for this very reason, fifty years can be a dangerous age. The temptation to dwell upon past achievement can harden the arteries of progress. At fifty, the will to challenge tomorrow's needs and tomorrow's difficulties vigorously and open-mindedly—as a youth with *nothing to lose* would challenge them—frequently grows weak.

There is one very good reason, however, why the beginning of a new half-century still finds Weston a typically *young* organization in its attitude toward new industrial wants, new methods for meeting them, and new techniques of manufacture. From the time when Dr. Weston sketched the design for the first Model 1 instrument, *pioneering became a deliberate Weston policy.* Before the phrase "industrial research" came into the language, *Weston engineers were busy at it!*

Now, after fifty years, pioneering has become an ingrained habit at Weston—unaffected by the rush demands of boom-times or the curtailments of leaner periods. So far this year, for example, four fundamental instrument improvements are going into production. Three more are in the test stage. A half-dozen others are on the drawing boards of the engineering department.

That is why, at the half-century mark, Weston is not stopping to "point with pride" at what *has* been accomplished in its first fifty years. Rather, we ask with a youthful enthusiasm we see no reason to suppress: Watch what Weston *is* doing . . . will *continue* doing . . . all during the next! . . . Weston Electrical Instrument Corp., 644 Frelinghuysen Avenue, Newark, N. J.

Electrical Engineering

Registered U. S. Patent Office

for May 1938—

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The Cover

Winding capacitors in the Pittsfield, Mass., works of the General Electric Company. Those attending the AIEE North Eastern District meeting, May 18–20, in nearby Lenox will have an opportunity to visit this plant

High Lights

Carrier System for Toll Cables. Constituting a symposium at the AIEE 1938 winter convention, a group of four papers by nine Bell System engineers described a new carrier telephone system for toll cables; all four papers and related discussions are published in this issue. The new system provides 12 channels on one pair of wires and has repeaters every 17 miles; no loading coils are used in these circuits (*Transactions pages 227–36*). Terminal apparatus for the new system has been designed to form a basic part of the terminals of other carrier systems now under development (*Transactions pages 237–44*). Quartz crystals are used as filter elements in the channel-selecting filters of the system, in order to obtain abrupt discrimination between wanted and unwanted frequencies and at the same time to secure low and uniform loss in the transmitted band (*Transactions pages 245–9*). Small adjustable mutual-inductance coils are connected between carrier pairs to balance out crosstalk; noise is kept at an extremely low level (*Transactions pages 250–61*).

Summer Convention. Members who have planned sometime to visit the Nation's Capital but who have not yet done so are offered an unusual opportunity to combine a sightseeing trip with attendance at the AIEE 1938 summer convention, which will be held in Washington, D.C., June 20–24. The technical program, details of which will be announced later, tentatively comprises ten technical sessions and six conferences. Inspection trips to many government buildings and points of historic interest in and near Washington are being arranged. The program will include also competitions for the Mershon and Lee trophies and other sports events and interesting social activities (*pages 221–4*).

Relays for Differential Protection. Large power transformers, a-c generators, and station bus systems commonly are protected by differential relays. Such relays sometimes are subject to false operation by differential currents not caused by internal faults in the protected equipment. The utilization of the harmonic components of these currents for restraint is said to afford an effective and generally applicable means of preventing false operation (*Transactions pages 262–71*).

Radioactivity. Spontaneous emission of radiant energy is a property possessed naturally by certain elements, as was discovered 40 years ago; more recently artificial means for inducing radioactivity in substances not possessing this property in nature have been found, and now a radioactive form is lacking for only one of all known elements (*pages 193–203*).

Current-Limiting Reactors. Although the use of current-limiting reactors is detrimental to the normal operation of electric systems, such reactors are valuable in contributing to the safety of systems during faults. Many plans to minimize the undesirable characteristics and at the same time retain the desirable protective features have been proposed (*Transactions pages 272–80*).

Lenox Meeting. A very informal stag smoker is one of the events on the program of the North Eastern District meeting to be held in Lenox, Mass., May 18–20, 1938, details of which are included in the final announcement. Speakers for the general session and for the mixed banquet also are announced (*page 224*).

Electronic Switching. Circuits may be made operative or inoperative by a change of polarity or magnitude, or both, by means of electronic devices, as well as by the more common physical opening and closing by circuit breakers and knife switches. One type of electronic switch offers control of a large number of circuits (*pages 209–20*).

Young Engineers. College graduates entering industry face many adjustments from campus life, and failure to meet them may result in dissatisfaction to the employer and disappointing progress for the engineer. A summary of 16 points of advice may guide the new graduate (*pages 206–08*).

Submarine Cables. Maintenance of the world's submarine telegraph cables is performed by ships specially equipped for this service; one such ship now is engaged in experiments to increase the protection of cables by burying them in the ocean bottom (*pages 204–05*).

Pacific Coast Convention. A joint session with the Pacific Coast members of the Institute of Radio Engineers is being planned for the AIEE 1938 Pacific Coast convention to be held in Seattle, Wash., August 9–12 (*page 225*).

Year Book. The AIEE 1938 Year Book has been issued and is available to members who have use for it (*page 225*).

Coming Soon. Among articles and papers now undergoing preparation for publication in early issues, are the following: an article describing a coaxial cable system for television transmission by M. E. Strieby (M'22); an article reviewing electrical precipitation by W. A. Schmidt (M'22) and Evald Anderson; an article on the use of electricity in medicine by R. E. Williams (A'35); a paper describing electron-tube theater-lighting control by E. D. Schneider (A'32); a paper describing a new type of metal-glass-porcelain seal for introducing electrical leads into sealed containers by W. E. Bahls; two papers on the use of electron tubes for the power supply and control of d-c motors by C. C. Clymer and R. G. Lorraine (M'36), and G. W. Garman (A'38), respectively; two papers on modern electric vehicles for urban passenger transportation by Thomas Fitzgerald (A'02) and R. H. Stier, respectively; a paper presenting data on discharge currents in lightning arresters on distribution systems by K. B. McEachron (F'37) and W. A. McMorris (M'37); a paper presenting operating results with a Petersen coil on a 100-kv line traversing mountainous country and exposed to lightning by W. D. Hardaway (M'32) and W. W. Lewis (M'13).

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Radioactivity, Artificial and Natural

By K. K. DARROW
ASSOCIATE AIEE

In a very few years after its discovery in 1898, radioactivity became and has ever since remained the most celebrated subdivision of modern physics. In addition to substances naturally radioactive, such as radium, others may be made so artificially; in fact, of all the known elements, hydrogen alone remains the only one of which a radioactive type has not been discovered or invented.

RADIOACTIVITY is a world-famous word relating to a world-famous subject. In general, when a statement of this sort is spoken, it is more than likely to be foolish; for specialists are altogether too addicted to imagining that their special interests are of world-wide concern when perhaps not fifty thousand people have ever even heard of them. With respect to radioactivity, though, the statement is correct. It would have been difficult indeed for any literate person to miss making the acquaintance of this word, in any year since 1900. I might say that radioactivity has been the best-advertised topic in modern physics—and this is not to say that it has been over-advertised! It is in fact the only part of modern physics which has received something approaching its due renown. Such good fortune cannot of course be altogether due to the fundamental values of the subject. A great part of the fame of radioactivity comes from medical applications and even more from medical hopes, and some from incidental things, such as the tragic end of one of its great students and the sex of two others. Still it is a matter for rejoicing that whatever the reasons may be, one portion of physics now enjoys its proper quota of the glory to which so many others are entitled.

The discovery of radioactivity took place in 1896. Quite a number of things of the highest importance to physics—and to humanity at large—were begun between 1895 and 1900, and of these the study of radioactivity was the second. The study of X rays was the first. The second was commenced only because the first had been, and therefore I speak of the first. Imagine a tube containing air and a couple of electrodes a few inches apart, and suppose that you have a battery which can supply a durable current at 10,000 volts or more, and an air pump as well. If the air is at atmospheric pressure, the 10,000 volts can be applied between the electrodes and nothing will happen. If with the pump you now reduce the pressure of the air to about a thousandth of the atmospheric value, the air which remains in the tube will become very luminous and splendid. If next you reduce the air pressure by yet another tenfold, the splendor will fade out, but now the glass of the tube itself, in the region opposite the negative electrode, will be shining with a pale green glow. This too is a beautiful sight, but decidedly not one to be enjoyed for a long time at close range, for it is attended by invisible rays very dangerous to health and even life. These are the X rays.

Many people have heard that Roentgen discovered the X rays because he kept some photographic plates in a box which happened to lie near the tube, and found one day that the plates were fogged. It is true that he did observe the fogging of plates by the rays; it is true also that for years afterward, people were telling in various parts of Western Europe and America how they too had noticed that their plates were spoiled when left by accident in the neighborhood of discharge tubes, but unluckily they had only felt annoyed and had resolved to keep their next batches of plates in safer places. However it was something else that led Roentgen to the discovery. He had in his laboratory some sheets of phosphorescent substances; and he found that whenever one of them was in the neighborhood of the tube it would shine; and what was more, *it would shine even when hidden from the tube by a sheet of black cardboard.* The X rays (as he presently named them) were able to pierce substances opaque to light, and to cause phosphorescent substances to shine. Roentgen very soon discovered other properties of the rays, but these were the earliest. Moreover the greenish glowing of the glass in the X-ray tube itself resembles the light of phosphorescence; so, here were two apparent connections between penetrating X rays on the one hand, and phosphorescence on the other.

Now we come to radioactivity. There was a man in Paris whose attention was caught by these facts, and his name was not Curie. Curie is the second great name in the story of radioactivity; the first is Becquerel. I put down his first name (Henri) as well, for Becquerel—like Curie and Bernoulli and Darwin and others—is the name of a dynasty of scientists, of which Henri was the third. Henri Becquerel seems to have reasoned after this fashion: "X rays and phosphorescence are found together; therefore, wherever there is phosphorescence, there may be rays like X rays." So he took photographic plates and wrapped them in dark paper, and then he took one phosphorescent substance after another and (after making them luminous by exposing them to light) laid them in succession beside the plates, and after an interval looked to see whether there had been fogging. Time after time the result was completely negative, but at last he came upon a chemical compound of the element *uranium* which was phosphores-

An address delivered before the New York Electrical Society, January 12, 1938, and scheduled to be delivered at the AIEE North Eastern District meeting, Lenox, Mass., May 18-20, 1938.

K. K. DARROW is research physicist of the Bell Telephone Laboratories, Inc., New York, N. Y. He received the degree of bachelor of science from the University of Chicago in 1911 and doctor of philosophy from that institution in 1917. During 1911 and 1912, he studied at the Universities of Paris and Berlin. Since 1917 Doctor Darrow has been in the employ of the Western Electric Company and Bell Telephone Laboratories. He has been engaged largely in writing on various fields of physics and the allied sciences.

Figure 1. Periodic table of the elements

Values of atomic weights taken from the seventh Report of the Committee on Atomic Weights of the International Union of Chemistry; G. P. Baxter and others, *Journal* of the American Chemical Society, volume 59, page 219

I	II	III	IV	V	VI	VII	VIII			O
1 H 1.0078										2 He 4.002
3 Li 6.940	4 Be 9.02	5 B 10.82	6 C 12.01	7 N 14.008	8 O 16.000	9 F 19.00				10 Ne 20.183
11 Na 22.997	12 Mg 24.32	13 Al 26.97	14 Si 28.06	15 P 31.02	16 S 32.06	17 Cl 35.457				18 A 39.94
19 K 39.096	20 Ca 40.08	21 Sc 45.10	22 Ti 47.90	23 V 50.95	24 Cr 52.01	25 Mn 54.93	26 Fe 55.84	27 Co 58.94	28 Ni 58.69	
29 Cu 63.57	30 Zn 65.38	31 Ga 69.72	32 Ge 72.60	33 As 74.9	34 Se 78.96	35 Br 79.916				36 Kr 83.7
37 Rb 85.48	38 Sr 87.63	39 Yt 88.92	40 Zr 91.22	41 Nb 92.91	42 Mo 96.0	43	44 Ru 101.7	45 Rh 102.91	46 Pd 106.7	
47 Ag 107.880	48 Cd 112.41	49 In 114.76	50 Sn 118.70	51 Sb 121.76	52 Te 127.61	53 I 126.92				54 Xe 131.3
55 Cs 132.91	56 Ba 137.36	Rare Earths	72 Hf 178.6	73 Ta 180.88	74 W 184.0	75 Re 186.31	76 Os 191.5	77 Ir 193.1	78 Pt 195.23	
79 Au 197.2	80 Hg 200.61	81 Tl 204.39	82 Pb 207.21	83 Bi 209.00	84 Po	85—				86 Rn 222
87—	88 Ra 226.05	89 Ac	90 Th 232.12	91 Pa 231	92 U 238.07					

Rare Earths

57 La 138.92	58 Ce 140.13	59 Pr 140.92	60 Nd 144.27	61	62 Sa 150.43	63 Eu 152.0	64 Gd 156.9
65 Tb 159.2	66 Dy 162.46	67 Ho 163.5	68 Er 167.64	69 Tm 169.4	70 Yb 173.04	71 Lu 175.0	

cent and which fogged the plate. It is not recorded that he shouted "Eureka!" but he had as good reason to do so as Archimedes. He had discovered the first-to-be-known example of radioactivity.

Now comes the strange and paradoxical part: Becquerel had arrived at his great discovery by following a false clue. There is really no connection whatever between radioactivity and phosphorescence, and it was purely an accident that a compound which was phosphorescent had happened to contain an element which was radioactive. In trying to make a simile for what then happened, I have adopted the rather frivolous comparison which follows. Suppose that you were to meet a man who was wearing a blue serge suit, and notice that he was speaking a foreign language—Swedish, let us say. For some reason this would interest you particularly, and you would decide to look for other examples of people speaking Swedish. You would begin by reasoning that "Swedish speech was associated with a blue serge suit, and therefore any man who is wearing blue serge may speak Swedish." You would then listen to everyone whom you passed in the street who was wearing blue serge, and the first few whom you heard would prove to be speaking English. This would prevent you from believing that a blue suit necessarily entails the speaking of Swedish; but you might continue anyhow, and eventually you might find another man who was wearing blue serge and speaking Swedish. Now if you were like some people, I am afraid you would send a communication to a scientific journal, announcing that it is a principle that everyone speaking Swedish is wearing a blue serge suit. But not if you were like Becquerel! If you were like Becquerel you would trail the man for weeks; and sooner or later you would come upon him wearing a grey suit or a brown one, and still he would be speaking Swedish. In the course of time you would doubtless come upon other people who never wore blue serge and yet spoke Swedish. Finally you would realize that it was just a piece of luck that you had happened to discover a man speaking Swedish, by making the fallacious assumption that all such men wear blue. Now in this case of Becquerel's, the phosphorescence was only a feature of the clothes which the uranium happened to be wearing, or more literally, the chemical compound in which it was involved. But the radioactivity was a feature of uranium itself and that is what Becquerel proceeded to prove; first by testing various other chemical compounds of uranium which were not in the least phosphorescent, and then by testing the pure uncompounded metal itself.

Uranium, then, is a radioactive element. But it is not the only one; there were numerous others, even in the days before the physicists had started making new ones. This is where the elder Curies enter the story: Pierre and Marie Curie, in 1898. First they measured the activity of uranium, pretty carefully. Then they started measuring the activity of various minerals containing uranium, and they found too much: these minerals were more active than they should be, by virtue of their uranium content alone. The Curies suspected that some other radioactive element was lurking in the depths, and they undertook to get it out. This was of course a chemical problem primarily, and as a matter of fact, their Nobel prize was the chemistry prize, and quite rightly. Eventually they isolated their new element, or rather, two of them, which they named "polonium" and "radium." Having at last got their radium and weighed it, they found that it amounted to only two parts in a hundred million (by weight) of the rock from which they had extracted it. They required three tons of the rock, in order to get one one-hundredth of an ounce of the radium. Two parts in a hundred million! and yet, while it was still dispersed in that almost incredible scantiness through the rock, they had already been able to detect it! This is the point which

I most wish to bring out, at this stage. A radioactive substance is far more easy to detect than any which is not. It is like salt in food, and the radioactivity is like the flavor of the salt, which shows the presence of a dash so insignificant that anything else in the food would go untasted if it were equally rare. Fortunately for us the instruments which are used to detect a radioactive body are not our tongues, but apparatus of a much less vulnerable kind.

Now I mention only one name before reaching the recent developments, but this the greatest name of all: RUTHERFORD. Rutherford was the first to understand radioactivity—the first to prove the contemporary atom-model—and the first to achieve transmutation. Any one of these achievements by itself would have secured undying glory to its author, but this great man made three. As lately as two years ago I wrote in a book that every leading figure in the history of transmutation was still living and still ardently at work. As lately as last October I could have repeated that, but now the master is gone—quite suddenly gone in the fullness of his powers. This lecture is in a sense a memorial to Rutherford, not because it was so designed, but because any lecture on the new radioactivity or on the old involves so much of his thought and so much of his work that it would be reduced to a few incoherent bits if everything not traceable to Rutherford should be left out.

The first achievement of Rutherford in this field was to identify the rays emitted by radioactive bodies. He identified three kinds, and gave them the names which they still bear and assuredly always will: *alpha*, *beta*, and *gamma* rays. The last-named (which are of the nature of light) are the ones whereby radioactivity was first detected, for they are the ones which fog the plates and produce the phosphorescence outside of a rather narrow space just around the radioactive substance itself. They are also the ones responsible for the great work already done in medicine by radioactive bodies, and on which (I am told) there is great reliance for the future. If this were a medical lecture the gamma rays would require most of its content; but as it is not, I leave them with this brief allusion, and turn to the others. The beta rays are electrons, which may be of either sign (Rutherford, like the rest of the world, was acquainted only with the negative ones until five or six years ago). The alpha rays are also charged particles, much heavier than electrons; I shall be defining them more exactly before long. The beta rays

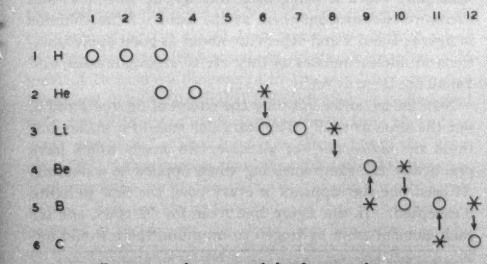


Figure 2. Isotopes of the first six elements

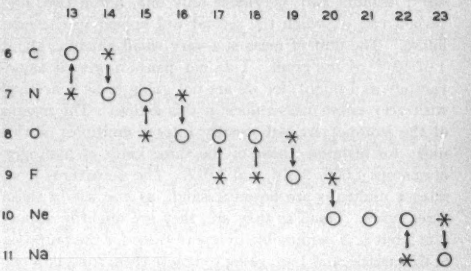


Figure 3. Isotopes of the elements numbered 6 to 11

and the alpha rays, and for that matter the gamma rays as well, are detected by very ingenious devices of which most types are electrical, though the particular type which supplies the photographs seen in this lecture is not.

Now at last I exhibit the list of the radioactive elements.

This list (figure 1) is none other than the veritable table of the elements itself! *Of all the known elements there now remains just one of which no radioactive form has yet been discovered or invented.* Hydrogen is the exception (the reader may say "Of course!" but it is not excluded that some day a radioactive type of hydrogen may be produced.) At the end of the list stands uranium, the first of the radioactive bodies to be discovered. It has stood there ever since Mendeleff set up the table in this fashion, but actually it now must yield its pride of place, for physicists have lately created radioactive elements which lie beyond it. I have though gone ahead too rapidly in speaking of these already. Once more let me state the marvelous fact that of all the known elements, every one but hydrogen exists in a radioactive form, many indeed in more than one.

In speaking of "forms" I have been alluding to something which the table as it stands in figure 1 does not make clear. Everyone recognizes the "chemical atomic weights" there appended to the symbol of each element. If an element has only one kind of atom, this figure is the actual mass of the atom, expressed in terms of a unit which I will presently define. There are such elements; beryllium and fluorine, sodium and aluminium are examples. Most elements however have two or more kinds of atoms differing in mass. Thus, in figure 1, the pigeonhole for hydrogen should contain three mass-values; that for helium, two; that for tin, no fewer than ten. It would make the table impossibly crowded to print them all in this way, and consequently I have broken it up into sections, of which figure 2 represents the first six elements.

In this figure each element has a row to itself, and each value of mass has a column to itself, and each circle represents a stable kind of atom. I now introduce the technical term "isotope" to distinguish the different kinds of atoms common to a single element. Hydrogen, you see, has three stable isotopes (there is some doubt about the stability of the third, though none about its existence); helium two (again there is doubt about the stability of

one); lithium two, beryllium only one, boron two, and carbon two of which the second will appear in the next figure. The unit of mass is a very small amount, about $1.67 \cdot 10^{-24}$ of one gram. I do not pause to give it as accurately as I might, for we are not going to be concerned with very exact mass-values in this article. The masses of the isotopes are not exactly integer multiples of this unit; for instance, those of the three kinds of hydrogen atoms are 1.008, 2.016, and 3.017. The departures from integer multiples are however small, as you see in these three cases. Small as they are, they are mightily important; but it is permissible to ignore them for the purposes of this article, and I am going to ignore them from now on. I will however write of the integers at the heads of the columns as "mass-numbers" rather than "masses."

Since the isotopes of an element differ in mass, what is it then that they have in common? I answer this question by describing Rutherford's second great achievement, the "nuclear atom-model." Rutherford was the first to prove that the atom consists of a positively-charged nucleus surrounded by a swarm of negative electrons. The nucleus is much more massive than the electrons, and this is one of the reasons for comparing the atom with the solar system, in which the sun is much more massive than the planets which perpetually swing in orbits around it. A less hackneyed and newer simile is that of Bragg (just now, by the way, appointed as Rutherford's successor in the Cavendish chair at Cambridge) who likens the atom to a man's head with a swarm of gnats buzzing around it. Normally—that is to say, when the atom is complete and electrically neutral—the negative charges of all the electrons put together just balance the positive charge of the nucleus. If Z be used to stand for the number of electrons in the normal neutral atom, and $-e$ for the charge of the negative electron, then $+Ze$ is the amount of the charge on the nucleus. Z is called the "atomic numbers" of the element in question. This it is, of which all the isotopes of any one element have the same value. This it is which distinguishes an element, and is common to all of the different atoms of that element whatever their masses may be. For hydrogen it is 1; for helium 2; for lithium 3; for uranium 92. Each row in figure 2 and figure 3 is marked on the left not only with the chemical symbol of the element to which the row belongs, but also with the atomic number thereof.

Radioactivity is a feature of the nucleus. This accounts for some of its remarkable aspects, which greatly surprised the world of physicists and chemists when they were first established. Being a quality of the nucleus, it varies from one isotope* to another of any element, much more drastically than does the mass. Being a quality of the nucleus, it is immune to the physical state of the atom—i.e., it is the same whether the atom is part of a solid, a liquid, or a gas; it is immune also to the chemical state of the atom, i.e., it is the same whether the radioactive element is isolated or is part of a chemical compound. It is also immune to heat and to all of the many other agencies which physicists and chemists have at their command.

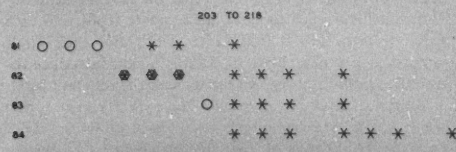
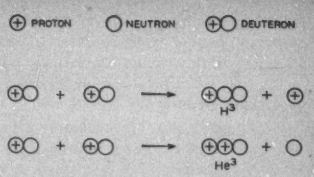


Figure 4. Isotopes of the elements numbered 81 to 84

Figure 5. Scheme of the deuteron-deuteron reactions



Radioactivity being a feature of the nucleus, every chemical symbol which I use from now on will refer to the nucleus of an atom and not to the atom as a whole. "Be" will stand for beryllium nuclei, "F" for fluorine nuclei, "Al" for aluminium nuclei. For most elements, though, there are two or more different sorts of nuclei distinguished from each other by their masses, and the symbol must tell us which is meant. The custom is to write the mass-number of the isotope in question as if it were an exponent: H^1 and H^2 and H^3 for the three kinds of hydrogen nuclei, He^3 and He^4 for the two kinds of helium nuclei, Li^6 and Li^7 to distinguish between the isotopes of lithium, and so on. If in addition one wants to remind the reader of the atomic number, one writes it as a subscript before the chemical symbol: ${}_1H^1$, ${}_1H^3$, ${}_2He^4$, ${}_9F^{19}$ and the like. Purists object that either the chemical symbol or the value of Z is superfluous when both are given, but others often like to see them both. And now for some names: there are three nuclei which have names of their own. The Greek words for "first" and "second" are applied to ${}_1H^1$ and ${}_1H^2$; they are the *proton* and the *deuteron*. The name for ${}_2He^4$ is *alpha particle;* this nucleus is indeed the particle which, as Rutherford discovered long ago, makes up one of the three kinds of rays which radioactive bodies emit, and there never was a greater piece of good fortune in language than that whereby this all-important particle received the name of the first letter of the Greek alphabet, for indeed it is the alpha of modern nuclear physics. And now another reference to masses: the mass of the electron (when not moving extremely fast) is only about 0.0005 of the mass-unit which is being used throughout this talk, and therefore the mass-numbers at the heads of the columns in figures 1 and 2 and others are about as good approximations to nuclear masses as they are to atomic masses, and I shall use them as such.

Now let us notice not only the circles of figures 2 and 3, but the stars as well. The stars also stand for nuclei, but these are *radioactive*—or *unstable*, two words which have practically the same meaning when applied to a nucleus. At least one star appears in every row, the first in figure 2 excepted. If the figure had room for 92 rows, one for each element from hydrogen to uranium, there would ap-

* Isotopes were first distinguished from each other (by Soddy) by virtue of their differences in radioactivity.

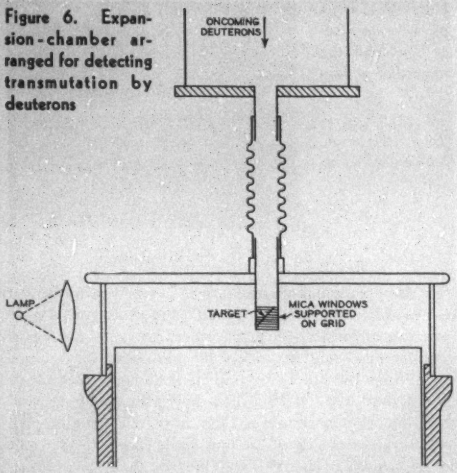


Figure 6. Expansion-chamber arranged for detecting transmutation by deuterons

pear at least one star in every row below the first, excepting three (atomic numbers 61, 85, 87) for which no isotope either stable or unstable is known with certainty and the element itself must still be regarded as missing. (Furthermore there should be at least three more rows numbered 93, 94, and 95, and containing stars but no circles.) This is what is meant by saying that every known element, hydrogen alone excepted, has at least one radioactive form.

Figure 2 shows that at the beginning of the table of the elements, the stable types of nuclei outnumber the unstable ones. The preponderance is gradually shifted as Z increases, and figure 3 exhibits to us how greatly the radioactive nuclei outnumber the stable ones among the elements of which the atomic numbers range from 81 to 84. Indeed the circle which is lowest and most to the right in figure 3 represents the most massive and most highly charged of all the stable nuclei which are known (it is the solitary isotope of bismuth, atomic number 83 and mass-number 209). All the rows after 83 are occupied entirely by stars.*

As the title of this article has already suggested, the radioactive nuclei are of two classes: the "natural" and the "artificial," the types already existing in the rocks of the earth and the types made in the laboratory by physicists employing the art of transmutation. Nearly all of the natural types lie beyond 80 in atomic number, and most of them were discovered in the first 15 years after Becquerel found the first. Two of them are identical with two of the man-made types. Apart from these two, every one of the artificial types is a creation of the years since 1933. One guesses that while the natural radioactive bodies may be many, the artificial ones must surely as yet be few; how surprising then to learn that while there are some 40 of the former, the latter after four brief years already number 230! Unlike the natural ones, these artificial isotopes are sprinkled liberally throughout the whole of the table of the elements, from the second onward to the end. Not only in number but in diversity of mass and charge are the artificial radioactive bodies now outstanding by far.

These artificial examples forming now so large and important a group among the radioactive nuclei, I make a digression to speak of some of the transmutations from which they are derived. The art of transmutation is already so huge a subject that the digression must be severely limited if ever we are to come back to radioactivity. I must therefore make only a passing allusion to the fact that the first of the new radioactive nuclei were made by bombarding various light elements with very energetic alpha particles. Here the second Curie generation must be introduced, for the daughter and son-in-law—Irene Curie and Frederic Joliot—of the first Curie pair were the ones who made this discovery. (It was not their entry into the field of radioactivity, they having already studied natural radioactive bodies for a number of years).

Returning to figures 2 and 3, notice that many of the radioactive isotopes lie just one step to the right of stable isotopes: Li^8, Be^{10}, B^{12}, C^{14}, N^{16}, 0^{19}, F^{20}, Ne^{23} are the examples found in these two pictures alone. It seems as though they might differ from their neighbors on the left—Li^7, Be^9 and so forth—by possessing an extra particle of mass (approximately) 1 and charge zero. If only one could find such particles roaming freely about in nature, might one perhaps succeed in adding them to the stable nuclei of lithium and beryllium and boron and the other elements and so produce these radioactive nuclei?

Such particles may indeed be found roaming about in nature, but not of their own volition. These "neutrons"—for such is their name—must themselves be set free by the art of transmutation. Free neutrons were first produced by bombarding certain elements with alpha particles; the discovery was an international one, and its story is interesting, but to keep this digression within bounds I

Figure 7. Tracks of a proton and a H^3 nucleus resulting from one of the deuteron-deuteron reactions

(P. I. Dee, Cavendish Laboratory; *Proceedings* of the Royal Society)

* It must though be admitted that some of the heaviest nuclei, though demonstrably radioactive, may exist for hundreds of millions of years before they disintegrate; "instability" is indeed a very relative concept!

must again content myself with giving the names—Bothe and Becker in Germany, Curie and Joliot in France, Chadwick in England—of those who carried it through its consecutive stages from first intimation to triumph. More than 100 different ways of freeing the neutron are already known, but of all this diversity I will take one only, which consists in projecting deuterons against deuterons.

The "deuteron-deuteron reactions"—D-D reactions for short—are produced by applying high voltage to deuterons (emerging from a discharge tube containing heavy hydrogen, in which some of the atoms are divested of their electrons and the nuclei are left bare) and then directing them across a vacuum against a target containing other deuterons. (The target may be some solid compound of heavy hydrogen, such as ice in which plenty of the hydrogen atoms belong to the isotope H^2; or it may be gaseous heavy hydrogen.) The high voltage is required, so that the impinging deuterons may override the electrostatic repulsion between the positive charges which they bear and the positive charges of the deuterons waiting in the target and come into contact with these last. Generally in transmutation, "high voltage" signifies volts by the millions. These particular reactions are however among the easiest to produce, and with less than 100,000 volts it is quite possible to liberate neutrons at such a rate that their peculiar qualities can be well studied. (One reaction indeed has been detectably produced at 8,000 volts, a figure so low that it arouses speculation as to what the course of physics might have been if the second isotope of hydrogen had been discovered say 30 years ago.)

To explain what is actually observed to happen, I ask the reader to imagine the deuteron as a composite of a proton and a neutron, as it is exhibited in figure 5. With this image in mind, one might well expect that when deuterons are hurled with great energy and speed against a plate of matter containing massive nuclei—lead, for instance—they would be broken in two. This has been sought for but apparently does *not* happen, showing that we must keep our imaginations under continual check by experiment. What *does* happen is displayed, for the impacts of deuteron against deuteron, in figure 5. It seems

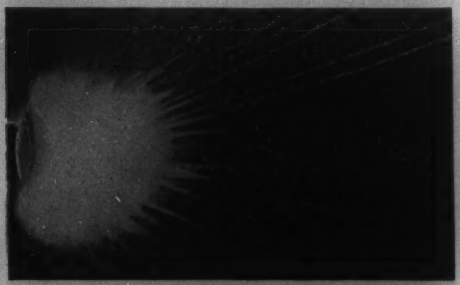


Figure 8. Tracks of protons, H^3 nuclei and He^3 nuclei resulting from the two deuteron-deuteron reactions

(P. I. Dee and C. W. Gilbert, Cavendish Laboratory; *Proceedings* of the Royal Society)

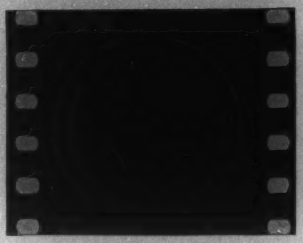


Figure 9. Track of a proton recoiling from the impact of a neutron

(I. Curie and F. Joliot, Institut du Radium; *Journal de Physique*)

that one deuteron is after all broken in two, but only under the condition that either its component proton or its component neutron adheres to the other. Another metaphor: one deuteron snatches either the proton or the neutron away from the other, leaving the abandoned neutron or proton to go free. Both of these descriptions are too figurative, but what is certain is this: from the scene of such impacts, particles of all the four kinds shown to the right of the arrows in figure 5 are observed to be proceeding. The labels show (what should already be obvious) that the newborn particles of mass 3 are isotopes of hydrogen or helium, according as they contain two neutrons and one proton or two protons and one neutron. I now show pictures to support these statements.

In figure 6 the apparatus is shown in a sketch: the cloud chamber or expansion chamber of C. T. R. Wilson, being the hollow cylinder which is shown below in axial section, its top being a glass plate and its bottom a piston head which can be pulled very suddenly downward by mechanism. Ordinarily the chamber is filled with moist but dustless air; when the piston head suddenly drops the air and the water vapor are sharply cooled by expansion, and the vapor condenses in droplets upon whatever ions may be floating in it. The side tube which enters the chamber from above is evacuated; through it come the impinging deuterons, to make their impacts upon the target at the knob-like closed end of the tube. The wall of the tube, thin as it may be made, is too thick to allow the deuterons to emerge into the air of the chamber. One might well expect that *a fortiori*, any new particles born out of the transmutation would be too slow-moving to pierce the wall; but many of these particles are much more energetic than the impinging deuterons themselves, for they draw upon a reserve of energy stored up in the nuclei.* They shoot through the wall into the air of the cloud chamber itself, and if they are charged, they make long trails of ions along their paths. The expansion is then produced and the water vapor, condensing upon these ions, makes trails of droplets which are the paths made visible.

Figure 7 exhibits two of these visible paths of "tracks," made by particles which sprang from the scene of the transmutation (inside the knob) in practically opposite directions but with very different penetrative powers, since one of the tracks is seen to be much longer than the other. The long one is the track of a proton, the short one is that of a H^3 nucleus which is a deuteron augmented by a captured

* In the sense employed in chemistry, these are "exothermic" reactions.

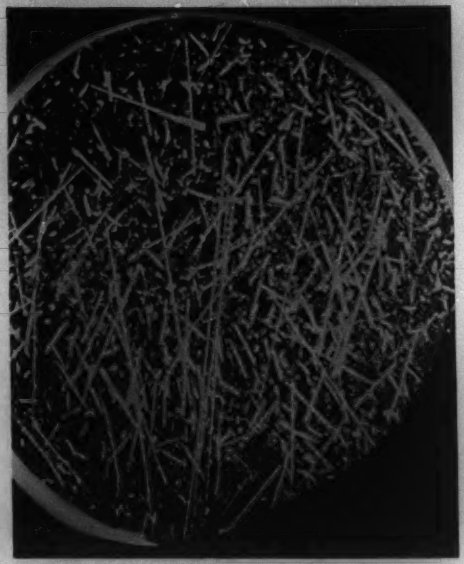


Figure 10. Tracks of protons recoiling from impacts of a dense stream of neutrons

(F. N. D. Kurie, University of California)

neutron: this picture shows a single example of the upper reaction of figure 5. How can physicists be sure that these tracks are due to the nuclei which I have named? This question is far too deep to be answered in this place, and I can only assure the listener that while such pictures by themselves cannot suffice for the proof, an unassailable proof can be and has been given by other and electrical methods of observing these newborn particles.

But how about the lower reaction of figure 6—the one which really concerns us, since all this digression is designed chiefly to exhibit the origin of free neutrons? In figure 7 no track appears which can be attributed to either a He^3 nucleus or a neutron and no such tracks appear in other similar pictures. The absence of He^3 is however due to a simple cause: these nuclei are born with insufficient energy to traverse the wall of the tube. To observe their tracks it is necessary to suppress the tube end, to fill the expansion chamber with heavy hydrogen in the gaseous form, and to project the deuterons directly into it. When this is done, all of the region of the gas which the impinging deuterons can reach becomes completely filled with the ions formed along their many tracks, and appears as a flare on the photograph (figure 8). Out of the flare project the tracks of the newborn nuclei. Those which stretch clear across the picture are in part those of protons, in part those of H^3 nuclei born from the first reaction. But in addition one sees a number of short tracks which terminate not far from the edge of the flare itself. These

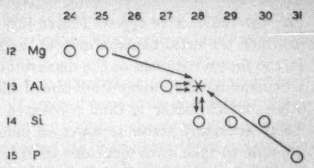


Figure 11. Various ways of making the radioactive nucleus Al^{82}

are the tracks of He^3 nuclei—not merely guessed, but proved, to be such.

Where however are the tracks of the neutrons? They are not seen upon this picture, nor in any; for neutrons make no tracks. Neutrons bear no electric charge, and hence they do not ionize the molecules of the air or any gas as they go through, for ionization is effected only by electrical forces which can tear electrons out of their places in molecules. Not making ions, they afford no footholds whereby the water vapor can condense and mark their passage. The expansion chamber is frustrated; and worse yet, so are the electrical devices which serve for detecting charged particles like fast protons or fast electrons, since they too depend on the ions which these can make. The neutron indeed might slip through all of our apparatus completely undetected, were it not liable to make collisions with nuclei so sharp and sudden that they may be compared with impacts of one billiard ball upon another. Comparisons with billiard balls are rife in physics, but seldom with so much justification. When neutrons are streaming through a gas, such impacts are suffered by nuclei of occasional atoms of the gas; and like a struck billiard ball, they recoil, and in recoiling they are able to make ions and the ions then serve to reveal them.

The track of such a recoiling nucleus, made visible in a cloud chamber, is seen in figure 9. This was taken soon after the discovery of the neutron, and at a time when these particles had as yet been released only by using natural radioactive substances to project alpha particles against various targets. Such ways of producing free neutrons are not very efficient, and accordingly one sees in the whole expansion chamber one track and one only (though I must interpolate that according to our present knowledge, many thousands of neutrons must have traversed this chamber without happening to strike any nucleus). See now the contrast with the present time, as illustrated by figure 10 which shows an expansion chamber traversed by the neutrons released when deuterons from a high-voltage machine bombard a target.* The machine in question was the famous cyclotron of E. O. Lawrence: there is no more striking illustration of the powers which this instrument has conferred upon the scientific world, over and above those which radium has already granted.

Our digression now ends, and we return to the artificial radioactive substances, being now equipped with knowledge as to how these—or rather, many of them—can be made. As I said earlier, many radioactive isotopes differ from existing stable isotopes only in possessing an extra neutron in the nucleus; and this extra neutron can be supplied to the stable nucleus, combining it and converting it

* This was another reaction than the one just mentioned, the target being of beryllium.

into the radioactive type. I have just exhibited one way in which the extra neutron may be, and often is, supplied. In the first-mentioned of the deuteron-deuteron reactions, a neutron is taken away from one of the deuterons by the other, which latter is thus converted from H^2 into H^3. There are many stable isotopes, of many elements, which are able to take away neutrons from impinging deuterons in this manner; a recent list gives no fewer than 50. The resulting nucleus-types are not in every case radioactive; several are stable, including H^3 itself (at least, no one has yet discovered evidence that H^3 is unstable, though there are doubts about it). Most however *are* radioactive. The reactions in question are known as (d,p) reactions, in allusion to the fact that deuterons enter the target and protons spring out. One might imagine that the deuteron consists of a proton leading along a neutron, which it pushes into the nucleus which it strikes, itself continuing its career as a free particle.

Neutrons however do not have to be escorted into nuclei by protons; those which are already free, such as the ones which are released in the second of the D-D reactions, are quite well able to creep in themselves and make themselves permanently at home. My use of the verb "creep" is not entirely fanciful, for the slower the neutrons are moving as they approach a target, the better their chance of entering its nuclei. Those fresh from their origin in reactions of transmutation are usually moving much too rapidly to be able to come to a halt in a nucleus—or to be liable to capture, whichever way of putting it one may prefer. It is necessary to interpose, between the source and the target, a block of paraffin or a can of water several inches thick. If the source consists of a natural radioactive substance bombarding another element with alpha particles and thus releasing free neutrons, the two may be mixed with each other and enclosed in a

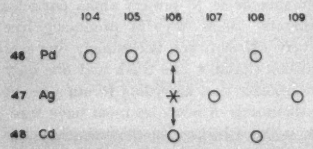


Figure 12. Illustrating an example of isomers

capsule which is then embedded in the center of a paraffin sphere or immersed in water. As the neutrons make their way out, they collide again and again with the nuclei of atoms in the paraffin or the water, and these recoil from the impacts. It is not however their recoiling which is now of importance, but the fact that at every such impact the neutron loses some of its energy. The point about choosing water or paraffin is that they are rich in hydrogen and consequently full of protons, and the elastic impacts of the neutrons against these entail a greater average loss of neutron-energy per collision than do impacts against any other nuclei.* There is good reason to believe that

* Energy transfer between an initially-moving and an initially-stationary elastic sphere is greatest when the latter is of the same mass as the former, and for protons and neutrons this equality of mass is realized within 0.1 per cent.

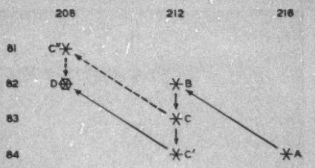


Figure 13. Part of the thorium series of radioactive nuclei. To make the sketch correspond to the actinium series, imagine each star moved one unit to the left

most of the emerging neutrons have energies no greater than those which the atoms of the water or the paraffin possess by virtue of their thermal agitation. These are the neutrons which are most effective in converting stable into radioactive nuclei by letting themselves be captured.

Even yet I have not mentioned all of the ways in which radioactive substances can be and are being made. Time does not suffice for commenting on the others, but some are exhibited in figure 11, which displays all of the stable but only one of the unstable isotopes of the four elements numbered 12 to 15. This one radioactive type, which I have tried to make more conspicuous by leaving out the rest, is the isotope 28 of aluminium—one of the few elements, which, very conveniently for physicists, has one stable isotope only. The arrows converging onto the star show the different ways in which Al^{28} is made. The two coming from the left signify that it is made by adding a neutron to the stable isotope Al^{27}; there are two of them, because the Al^{27} nucleus can either absorb a slow free neutron or annex the neutron from an impinging deuteron, whichever it has the opportunity of doing. The arrow slanting downward from the left signifies that Al^{28} can be made by bombarding magnesium with alpha particles: some of these are absorbed by nuclei of the isotope Mg^{25} which thereupon at once emit protons. The arrow slanting upward from the right signifies a process in which phosphorus is bombarded by neutrons (fast ones, in this case!) and some are absorbed by the nuclei P^{31} which thereupon eject an alpha particle apiece. The arrow pointing straight up signifies a process in which silicon is bombarded by neutrons; some are absorbed by nuclei Si^{28}, which instantly throw out protons. With no fewer than five ways of making a single radioactive type at his command, the physicist is in a position of power which seems all the more remarkable when one recalls that as lately as five years ago he had not (knowingly) made any radioactive substance by any way whatever.

Consider now the arrow pointing away from the solitary star in figure 11, and the arrows pointing away from the many stars in figures 2 and 3. These signify what is really meant by calling an isotope "radioactive." *A radioactive nucleus is one which spontaneously changes itself into a nucleus of another element by emitting a charged particle.* (Usually it lasts an appreciable time before it does so, and this delay is to be mentioned in a complete definition of the word "radioactive".) The arrows pointing away from the stars will serve to specify these changes. All in these figures are vertical: every one of these unstable isotopes transforms itself by emitting a particle of which the mass

is very small (compared to the mass-unit which we are using) while the charge is $+e$ or $-e$, according as the transformation is to the element preceding or to the element following. These particles are positive and negative electrons. All of the man-made unstable nuclei are radioactive after this fashion, being electron-emitters; and so are more than half of those which are found in nature.

What decides whether it shall be a positive or a negative electron which a given nucleus-type emits? Physicists cannot explain this as yet, in any adequate sense of the verb "to explain"; but we can readily see the law which governs the choice by examining the pictures. In figures 2 and 3 it will be seen that from each star the arrow points in whichever sense—upward or downward—it finds a circle to point at. Becoming completely animistic for the moment, I may say that the unstable nucleus wants to be stable—knows that one of its two neighbors, of identical mass-number but greater or lesser charge, is stable—knows *which* of the two is stable—and deliberately proceeds to identify itself with its stable neighbor by emitting an electron of the necessary sign. Putting the situation more drily: each of these unstable nucleus-types tends to transform itself into its adjacent stable isobar. Here "isobar" is a technical term for "nucleus of the same mass-number," and "adjacent" is a short way of saying "belonging to the preceding or the following element."

Suppose the star has circles both above and below it, i.e., that both of the adjacent isobars are stable (and prove themselves so by existing in nature): how will the unstable nucleus resolve its dilemma? Such cases are rare, but not entirely absent. An example appears in figure 12. The elements palladium and cadmium have isobaric isotopes of mass-number 106, in spite of the fact that their atomic numbers (46 and 48) are not consecutive: silver, with atomic number 47, lies between. There is no stable silver isotope 106, but a radioactive one can be and has been created, and for this the dilemma is posed. It handles the dilemma by grasping both horns! Electrons of *both* signs come out of the radioactive silver. I must say that there is something which indicates that the nuclei which make one choice may be slightly different (in mass, for instance) from those which make the other. It may therefore be well to speak of silver as having two isotopes of the same mass-number 106, and a word has already been coined: they are called "isomers" of one another. This does not alter the fact that where alternative choices exist, both are elected.

On figure 2 we notice an arrow which points to a vacancy. No stable nucleus Be^8 is known, though there has been a very diligent search for it conducted by many ways in many places. Practically no doubt exists that Be^8 bursts of itself into two pieces (two alpha particles) almost as soon as it is made. We thus have here an unstable (radioactive) nucleus—Li^8—which does *not* find stability by ejecting an electron, but instead hastens onward to a completer ruin. In the lower reaches of the table of the elements there are so many stable isotopes that the unstable ones can almost always turn themselves by one electron emission into one or another of these, and such catastrophes are rare. Among the natural radioactive substances in the upper reaches of the table they are common, as I now show in returning to natural radioactivity for the close of this article.

Notice again figure 4, in which the stars are so many and the circles so few. If arrows were to be inserted to show the transformations, they would crisscross into a maze. I have therefore separated the figure into three: all of the circles, stars, and rosettes in it will be found in figure 13 (which is really a pair, as the inscription says) and figure 14.

Taking figure 13 as it stands, we see five of the stars and one rosette of figure 4, connected by arrows: each star marks a nucleus which transforms itself by emission of a particle into the one next following along the arrow-chain. The rosette stands for a stable nucleus, and would be replaced by a circle were it not distinguished by being the terminus of such a chain. These five radioactive isotopes and one terminal nucleus-type belong to the "thorium series," and are known as thorium A, thorium B, thorium C, and so on, according to the letters which adjoin their stars. This is an unlucky bit of terminology, for it suggests that all are isotopes of the same element, which is clearly far from the truth.

Taking figure 13 again and imagining each star moved by one unit to the left (so that e.g., the star A goes to 217), we now are thinking of five more stars and another rosette of figure 4, duly connected by arrows. These constitute (a part of) the "actinium series" and are known as actinium A, actinium B, and so forth.

Taking figure 14 as it stands, we find ourselves confronted by eight more of the stars and the last rosette of figure 4, connected by arrows. These constitute a part of the "radium series" and are known as radium A, radium B, and so on. The "so on" covers more than it did in the other two cases, this chain continuing to the terminus here marked as radium G, though usually known by a different name.

Surveying the scene of these *massive* radioactive nuclei, one is struck by the fact that not all of the arrows are vertical. Many are slanting, and by their slant and their length they show that they represent the emission of alpha particles. It is a feature of some (not of all) of the unstable nuclei of mass-numbers greater than 200, that they strive toward stability by emitting these. For this feature we should be very grateful, since it was by the use of alpha particles from natural radioactive bodies that Rutherford achieved the first of transmutations; though physicists

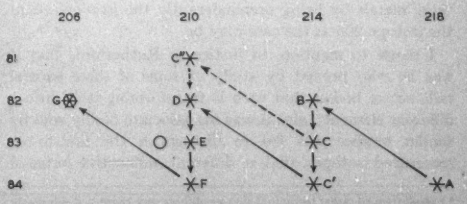


Figure 14. Part of the radium series of radioactive nuclei

now can transmute without their aid, no one can guess how long they would have waited without trying had they not had that encouragement. Vertical arrows also are seen, but again there is a contrast to the lighter isotopes; all of the electrons emitted by radioactive nuclei of mass-numbers beyond 200, or by natural radioactive isotopes of whatever mass, are negative. But for the fact that positive electrons had been observed among the cosmic rays in 1932, they would have been discovered along with the first examples of artificial radioactive isotopes in 1934, and what a sensation that would have been!

More than by anything else, probably, one is impressed by the concatenation of these radioactive nuclei. A long journey to stability lies ahead of thorium A and actinium A, a longer one still ahead of radium A; but the total lengths of the journeys are greater yet, for they begin further back. In figure 15 we behold the three series of radioactive isotopes in their entirety, and it is seen that the three "A-products," as they are called, are midway in the evolution and not at its beginning. The manner of drawing of this figure is changed from the preceding, atomic number being laid off along the horizontal axis and mass-number along the vertical; also, crosses and circles and dots are used to mark the members of the actinium, radium, and thorium series, respectively, and have no bearing on stability or instability. The actinium series should lie lower than it is drawn, with its terminus AcD lying midway between ThD and RaG; the mistake is incurred so as to diminish the overlappings which would otherwise confuse the picture.

Except for a few created in the last three years by transmutation, every known nucleus-type of mass-number greater than 209 and atomic number greater than 83 (as well as a few of slightly lower values) is found in figure 15. It appears that 83 and 209 are critical values of nuclear charge and mass, beyond which the constituents of nuclei —neutrons and protons, presumably, and whatever others there may be—cannot unite into stable systems.* All of these nuclei beyond 209 which are found in nature are seeking for stability by the emission of particles, but never finding it until they have emitted sufficiently many to convert themselves (or rather, the residues of themselves) into one or another of the three isotopes of element 82—*lead*—which are marked by rosettes in figure 4. For an obvious reason these three are called thorium lead, actinium lead, and radium lead. "Ordinary" lead as it comes from most mines is a mixture of many isotopes, but the lead which is found in close association with thorium or with uranium proves its origin from vanished atoms of these metals by being preponderantly the isotope 208 or the isotope 206 as the case may be.

I pause to mention, in justice to Rutherford, that it was he who proved by study of some of these natural radioactive bodies that each is transforming itself into a different element; also it was his associate Soddy who by similar studies was led to distinguish the first-to-be-recognized isotopes, that is, different radioactive forms of one and the same element. The way for making such diagrams as figures 2 and 3 and 4 was prepared before 1910 by these two men, though some of the facts embodied in figure 4 were not then available because of want of knowledge of atomic numbers, and all of the knowledge embodied in figures 2 and 3 was nonexistent because no radioactive isotopes of these elements had yet been created and nobody knew as yet how to distinguish their stable isotopes. Also it should be mentioned that only the extraordinary potency of radioactive substances in affecting our instruments of measure enables the physicist or the chemist to recognize the element to which a radioactive isotope belongs, nay even to detect its presence. With radium and a few others, it has been possible to amass enough of the substance to see and to weigh; with the great majority of natural and with the totality of artificial radioactive isotopes, nothing of the sort has even been approached, and we should still be unacquainted† with them if they had been stable.

Three examples of transmutation which occur in these upper ranges of the periodic table deserve to be recorded in even so brief a report.

In figure 14, notice the circle in row 83 and column 209 which (as I earlier said) represents the highest stable nucleus—bismuth 209. Radium E, represented by the star to its right, is clearly bismuth 210; by the testimony of its mass-number and atomic number, it differs from stable bismuth nuclei by the possession of an extra neutron. If bismuth should be bombarded by neutrons, either free or bound into deuterons, would it be transformed into radium E? Livingood at Berkeley did bombard ordinary bismuth with very energetic deuterons, and did succeed in producing a radioactive substance which agreed with radium E not only in emitting negative electrons, but also in converting itself into a substance emitting alpha particles, and the agreement extended to details of the emission. No doubt exists that he was making radium E out of bismuth 209 by enabling deuterons to transfer their constituent neutrons to this latter, just as H^3 is made from H^2 in the first of the deuteron-deuteron reactions.

In figure 15, notice that all of the members of the thorium series have mass-numbers divisible by 4, or equal to $4n$ with various integer values given to n. This is accordingly called the "$4n$ series," and one readily sees what is meant by calling the radium and the actinium series by the names of "$4n+2$" and "$4n+3$" series, respectively. One begins at once to wonder whether there is not a "$4n+1$" series. Such a series was long sought after in vain, and no member of it has yet been discovered in nature; but in the laboratory of the Curies in Paris thorium has lately been strongly bombarded by neutrons, and a new sequence of radioactive bodies has thus been engendered which has already been followed through several steps, and is in all probability the series so long missing.

As to the remaining feat—the creation of elements beyond uranium—it is now beyond doubt. Fermi and

* I recall from an earlier footnote that some of these very heavy nuclei (notably thorium 230 and uranium 238) are so very long-lasting that "unstable," while strictly correct, seems much too strong a word for them.

† This statement should be qualified slightly, for some of the artificial radioactive nuclei spring from reactions of transmutation which are so well understood that the observer could justifiably infer the existence of the nuclei in question even if he did not observe them.

his school at Rome, Hahn and Meitner in Berlin, Curie and Joliot in Paris have all borne witness to it. In one way it seems the most romantic of all the feats of transmutation, for nature had apparently set 92 as the limit of nuclear charge, and now man has transgressed it. The process is begun by exposing uranium to bombardment by streams of neutrons. It appears that when a uranium nucleus has captured a neutron, it finds itself not strongly enough charged to hold together, and proceeds to emit one negative electron after another in its search for stability. Each emission transfers the nucleus to an element one step higher, without affecting its mass-number; and the authorities agree that there are at least four consecutive emissions, after the last of which the atomic number is 96! This addition of four new elements to the periodic table opens a new field to chemists, one which they can scarcely have expected ever to be able to enter. The four have no proper names as yet, a curious circumstance in view of the fact that discoverers of new elements have thus far been in great haste (sometimes too great haste) to name them. Mendeleeff long ago used to denote an expected but undiscovered element by prefixing "eka" to the name of the element just above the vacant place in the periodic table; these new four are sometimes called eka-rhenium, eka-osmium, eka-iridium, and eka-platinum, but on looking at such words one is inclined to prefer the atomic numbers.

Now to summarize. The world as we knew it before the days of transmutation was constructed out of some 250 kinds of atoms, each consisting of a nucleus surrounded by a family of electrons. Of these 250 kinds of nuclei the great majority were stable and perpetual, but some 40 were unstable—doomed to perish in due time, by ejecting either alpha particles or negative electrons. These were the natural radioactive bodies. To these 40 kinds of radioactive nuclei already found in nature, physicists have added in a scant four years no fewer than 220 new ones by the art of transmutation. Every chemical element which is known to exist at all, with the sole exception of hydrogen, has at least one radioactive type of nucleus or isotope, and many have more than one. These man-made radioactive nuclei are often made simply by adding neutrons to nuclei which already exist and are stable. There are however other and more complicated processes, in which neutrons or protons or deuterons or alpha particles impinge on nuclei and seem to enter them, and other particles leap out. Many radioactive bodies have already been made in two or three different ways, some in as many as five.

Few things are riskier than to suggest a limitation either on the scope of nature or on the possibilities of science, and many a scientist is remembered chiefly for such a suggestion which later the course of events proved foolish. Yet there are circumstances in this case which give some ground for suspecting that already we may know nearly all of the stable and may have created nearly all of the radioactive nucleus-types. Several hundreds of types have now been made by the art of transmutation, but of them nearly all which seem to be stable are not new, and nearly all which are new are radioactive. This implies that the earth has already been stocked with almost all the stable nucleus-varieties, but not necessarily that we have yet come near to making all of the possible radioactive kinds. There are however reasons for believing that most of the remaining types have so little durability, that even if they were to be made they would not last long enough to be identified as radioactive. Nature probably has come quite close to building all the imperishable forms; we possibly almost as close to creating all of those which are capable of a little but not a perpetual life. Perhaps it is fitting that people who are not immortal should not be able to construct new elements which are immortal; but we at least can rejoice in having diversified the scene of the world with a surprising number of new substances which are none the less remarkable for being transitory.

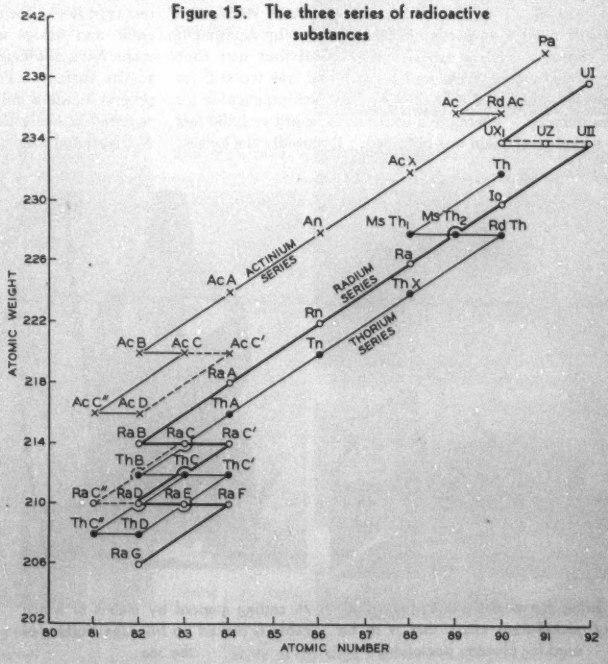
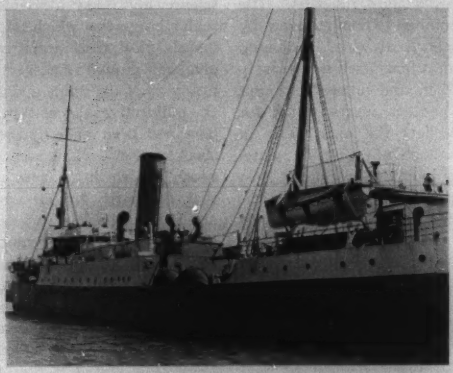


Figure 15. The three series of radioactive substances

Protection of Submarine Cables by Placement "Underground"

DAMAGE estimated at $500,000 a year is caused to the transoceanic telegraph cables of the world by the heavy drags or otterboards which are attached to fishing nets dragged along the ocean bottom by steam trawlers. To protect cables in waters where they are exposed to this hazard and thereby reduce this loss, a plow has been devised by engineers of the Western Union Telegraph Company which when pulled along the ocean bottom is expected to cut a furrow, drop the cable into it, and back fill over the cable. The first cables scheduled to be plowed under are in the fishing banks off the coast of Ireland, where damage is particularly severe.



Cable-repair ship "Lord Kelvin"

One of the major necessities for this work was a tow line capable of withstanding a 65,000-pound stress, and flexible enough to permit its management by equipment on the ship. Early experiments showed that wire rope developed torque when under strain and was too stiff for easy handling, and that only a chain was practicable for this purpose. Therefore a continuous length of 4,200 feet of nickel-steel chain was obtained. Reputedly the longest chain ever manufactured in one piece, it comprises 12,500 links, and weighs 43,000 pounds. The chain recently was loaded on the *Lord Kelvin*, flagship of the Western Union cable-repair fleet, during its first visit to New York Harbor since its construction in 1916; at this time the photographs reproduced in the accompanying illustrations were obtained.

The *Lord Kelvin* is a 332-foot oil-burning ship with a loaded displacement of 5,500 tons, and carries a complement of 85 men. In addition to machinery for paying out and picking up cable, other special equipment for repair work is provided, including testing equipment for determining the location of cable faults. Two general types of grapnels for raising cables are carried; one type hooks the cable, and the other hooks and cuts the cable and brings up only one end, since cables in deep water have insufficient slack to permit a loop to be brought to the surface. Four cable tanks provide capacity for several hundred miles of cable, of which several types are required in order that any type in use may be replaced. Navigational aids include depth and range finders.

Loading the specially designed 4,200-foot nickel-steel chain that is to be used for plowing operations

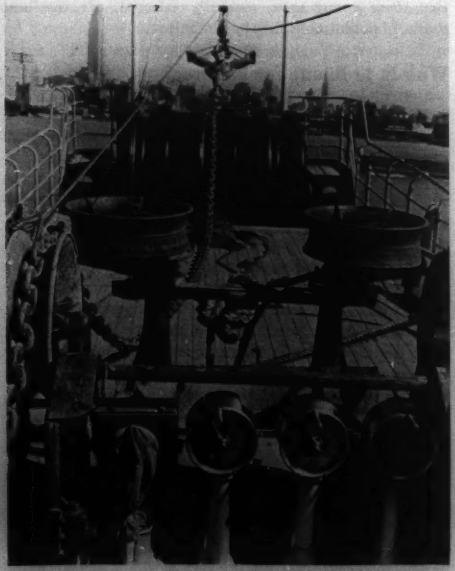
A cutting grapnel by means of which cable is picked up from the bottom of the sea

Cable marker buoys; largest weighs one and one-half tons and can support a safe load of four tons

Cables may be damaged by a variety of causes, ranging from icebergs to marine borers. When a break occurs in a cable, the position of the rupture may be determined by measurements of the electrical resistance of the conductors; records show that more than 50 per cent of the positions may be determined within 0.5 nautical mile. The route of the cable being known from astronomical observations which are taken continuously during the laying of all cables, the latitude and longitude of the position where the cable is broken are obtained. Upon reaching this location, the repair ship moors a mark buoy as nearly as possible over the position of the cable, and passes and repasses at a speed of about one mile per hour at right angles to the line of the cable until the cable is hooked.

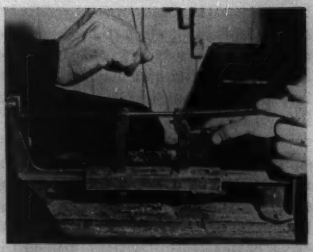
Splicing a broken cable is the most delicate operation aboard a cable ship. After joining the conductors of the two cables to be spliced, they are wrapped with successive layers of fine copper wire. Each layer of wire is soldered, after which the conductor is sheathed in gutta percha. In the tropics a hose is played on the cable to prevent the gutta percha from softening and permitting the conductor to become decentralized in the gutta percha; the cable carried by the ship in the cable tanks is kept under water in warm climates for the same reason. Moisture, however, must be kept out of the splice; trouble may be caused even by perspiration from the splicer's hands.

Cable that has been plowed into the ocean bottom will require a different technique for locating and grappling. This problem is being given careful study.



Foredeck of the "Lord Kelvin" showing cable bow sheaves and deep-sea cutting grapnel

The only tent at sea is erected aboard cable ships for the delicate work of splicing cables



After joining the conductors, successive layers of fine copper wire are applied

Each successive layer of wire is soldered; here the joint is being heated by a spirit lamp

Soldering a splice

Covering a splice with gutta percha

Testing a cable splice

Some of the steps necessary in splicing cables

The Young Engineer's First Years in Industry

By FRANK L. EIDMANN
Member ASME

Personal merit long has been recognized as the most important factor in the selection of people for unusual opportunities. Personal opinion may vary widely as to where responsibility for development lies, but no young engineer can do better than to assume it himself. The suggestions summarized at the end of this article are logical conclusions based on careful study and rationalization of opinions of people sympathetic to problems of adjustment. They should be of interest to every graduate.

HOW WELL satisfied are industrial executives with the young engineering graduates whom they employ? In visiting a large number of industrial plants over a period of years I have raised this question. Recently, I also sent a questionnaire on this subject to executives of 60 well-known manufacturing companies in many lines of industry, such as machine tools, locomotives, paper, steam turbines, electrical equipment, brass and copper, Diesel engines, automobiles, cameras, power-plant equipment, abrasives, steel, chemicals, watches, clocks, heating and ventilating equipment, shoe machinery, packaging machinery, drive chains, cash registers, ball bearings, instruments, typewriters, taps and dies, elevators, and special machinery, and also to public utilities, consulting engineers, and railroads. Replies were received from nearly all. In answer to the question, "How many of these young engineers turn out to be satisfactory?", the largest number of replies gave estimates of between 50 and 90 per cent. A few stated that only ten per cent prove satisfactory, and two companies are satisfied with all of the young engineering graduates whom they hire.

How about the young engineers who do not prove satisfactory? What is wrong with them? The answers indicate almost unanimously that personal traits and attitude rather than lack of technical training or ability are responsible. The principal fault seems to be the "inability to get along with their associates," or the "lack of ability to fit in quickly with their fellow employees and to make friends readily." The criticism mentioned in the next largest number of replies is "overeagerness for advancement." Other criticisms are: "Unwillingness to prepare for advancement over a long enough period," "lack of aptitude for engineering work," "inability to adapt themselves to the routine of operating work and at the same time avoid getting into a rut," "lack of initative," "inability to grasp the practical aspects of problems and situations," "impractical and unable to apply themselves," and "lack of willingness to work."

You would be justified in asking just what is meant by the term "unsatisfactory" as used in this article. Some of the executives made this clear by stating that probably 70 to 90 per cent of the young men turn out to be reliable routine workers, and, so long as their work does not fall below a reasonably exacting standard, they are retained. Only a small percentage of the men, however, turn out to be satisfactory in the sense of measuring up to expectations. Industry expects that, after a reasonable period of orientation, these young engineers will accept responsibility, show initiative and enthusiasm, and make more rapid progress than young men without college training who have come up through the shop positions.

It is to be emphasized that most of the executives, with whom I conferred or who responded to my questionnaire, show a keen and sympathetic interest in young college-trained engineers and offer their comments and criticism in a friendly spirit and with the hope of being helpful. They recognize the need of these young men as recruits in their organizations and would like to employ more of them than they do at present. Although some executives have become so discouraged in their experiences with young college men that they have definitely decided not to hire them until they have had a few years of experience with other companies, most industrial executives still believe that these young men, carefully selected, are the best source of potential leaders for the future.

Who Is to Blame for Failures?

In some of my interviews with executives, I raised the question concerning the responsibility for such a large percentage of the young engineers turning out to be disappointments to their employers. I asked whether the colleges are to blame, whether the trouble lies with the young men, or whether the employers are largely responsible. As previously mentioned, industry attributes most of the difficulty to the personal traits and attitude of the young engineers. A few employers place part of the blame on the colleges. None of them has suggested that he, himself, might be responsible. From my observations, I have come to the conclusion that the responsibility for the low percentage of young engineers who make good in industry lies in all three directions, that is, the young man,

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Essential substance of an address scheduled for presentation at a meeting to be held under the auspices of the junior group of the metropolitan section of The American Society of Mechanical Engineers, New York, N. Y., May 12, 1938. Published also in the May issue of *Mechanical Engineering* under the title "The Engineering Graduate's First Years in Industry," and made available here through the courtesy of George A. Stetson, editor of that publication.

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the college, and industry. It is apparent, also, that considerable misunderstanding frequently exists on the part of all three. Some of the young men have false notions as to their importance, the rate at which they should be advanced, and the value and importance of practical experience gained over a period of years by men who may lack college education. The colleges may fail to recognize the difficulty of the raw graduate to adapt himself to industrial life; may fail to inform the student as to the requirements of industry, the rate of advancement that may normally be expected, and the value of a college diploma; and the methods of selecting students may be poor, with the result that some young men do not know until after their graduation from college that they have not the aptitude for engineering work in industry. Some employers take it for granted that the college-trained engineer is trained in detail for industry and are disappointed when they find that this is not so. They fail to provide training and supervision that are essential for these young men during the period of readjustment from college to industrial life.

It is unfortunately true that many college-trained engineers fail to attain more than mediocrity in industry. But similarly in all professions, lines of work, and walks of life, the percentage of individuals who are outstandingly successful is indeed low. In fact, my observations convince me that the engineer's record compares favorably with that of other professions.

For engineers as well as for individuals in practically all other lines of endeavor, the leading hinderances to success are due to personal traits rather than to the lack of technical ability. Recently the American Banking Institute made public the results of an investigation of the causes of discharge of 4,000 office employees of 76 important firms. The survey showed that only ten per cent of those discharged lost their positions because of lack of ability to do their work. The other 90 per cent were discharged for reasons of a nature personal to the employees, such as carelessness, laziness, lack of co-operation, dishonesty, and lack of initiative.

Where the Young Engineer Is at Fault

It is true that many college-trained engineers are impatient for advancement, many have exaggerated ideas as to their worth to the company, and some take a superior attitude toward their fellow workers who have not attended college. These ideas and attitudes are, of course, not confined to engineers. The high-pressure recruiting methods that are followed by some firms are partly responsible for the student's mistaken ideas of his importance. Personnel officers start coming to the colleges as early as November to interview seniors, and some firms make tentative selection of the engineers fully two years before they graduate. In spite of the prevailing business conditions, all of the mechanical-engineering students who graduated from Columbia University last June had definitely accepted positions before the preceding February. Some had as many as three offers from which to choose. One student had been selected two years previous to his graduation. Part of the responsibility for the false notions of importance, therefore, clearly rests upon industry. College faculties must also share this responsibility when they allow these young men to go out into industry with mistaken notions. Students should be informed that recognition in industry comes only as the result of accomplishment which is achieved by long hours of hard work. Every student should also understand that the bare fact that he graduated from college entitles him to nothing, but that it will give him a tremendous advantage over his noncollege associates in opportunity to forge ahead. It should be pointed out to the student that, while he has been spending years in college, other keen, capable young men of his age have been receiving a practical training in industry, have become well acquainted and firmly entrenched in the organization, and have probably done considerable reading and studying. Not only must the college-trained man compete with these men who have a practical training, but he also has to make the sudden and severe adjustment from campus to commercial life. Perhaps he may even have an attack of homesickness. This is, therefore, a critical period in his career and many times does he become discouraged with his progress, especially when he hears of classmates and other friends who may be progressing more rapidly.

Before he leaves college, the young man's attention should be called to the complaint so often heard as to the superior attitude of college graduates toward noncollege men in industry. Although some college graduates do make this mistake, I have found that it is a matter of imagination on the part of many noncollege men. Nevertheless, the college man must be careful to avoid giving this impression. The matter of impatience for rapid advancement will take care of itself if the college and the employer will make it plain to the young man that it takes time and effort for the raw graduate to orient himself to the new work and that he must prepare himself and show himself ready for advancement. The company, especially, can do much to prevent misunderstanding by letting the young engineer know what progress he can normally expect to make if his services are satisfactory. It also should closely observe and supervise the young man in his work and relations with fellow employees and inform him, from time to time, whether his progress is satisfactory and in what way he is considered weak.

Lack of aptitude for engineering work is one of the reasons given for disappointment in the progress of young engineering graduates. We are also told that many students in engineering schools are not properly qualified and do not have the proper aptitude for engineering. Both statements are unfortunately true and are sad reflections on the selection by engineering schools and by industry. I look for the day when *engineering-aptitude* tests both by engineering schools and by industry will become important factors in selection of young engineers. Let me emphasize that I mean engineering-aptitude tests and not the usual intelligence, psychological, and achievement tests.

It is significant that so many firms find that students who have spent their summers working in industry, and students of co-operative engineering courses become so

much more quickly adjusted to their work after graduation and that failures among these men are fewer. These students naturally know what to expect when they enter industry and they know also, whether or not they are suited for this kind of work.

Industry's Responsibility

Many firms operate so-called training courses or programs for engineering graduates. Most of these consist essentially of having the young graduate serve for a short period in each of the departments of the plant. Unfortunately in most cases, the young man is allowed to shift for himself during this period, without encouragement, guidance, supervision, or training. He is compelled to pick up what information he can in a hit-or-miss way. As a consequence, many graduates flounder hopelessly for several years during this early period in industry, which is probably the most important in their industrial career. It is during this critical period that the severe adjustment from campus to commercial life must be made. New friendships have to be formed, and the young man is thrown on his own resources usually for the first time in his life. A carefully planned program under guidance and supervision shortens considerably the time required for training and personal adjustment, better prepares the young engineer for his work with the company, and greatly decreases the number of cases of dissatisfaction. I know of instances in which engineering graduates were discouraged and underpaid, their ability was unappreciated, and they made little progress under their first employer. These same men responded quickly and made more than average progress under their second employer, who offered guidance, encouragement, and instruction.

When hiring a college graduate, I think the company should make it plain that no assurance is given of a responsible position, progress will depend entirely upon accomplishment and attitude, and the college degree does not bear as much weight as the young man probably thinks it does. The young graduate should also be given an idea as to what progress he can normally expect to make if his services are satisfactory. Many students seem to have a wrong idea of what to expect.

Compensation is an important matter. The salary scale should be a fair one and provide for periodic increases. Some companies pay the beginner $175 or more per month, while I know of others that pay as low as $16 per week. It is certainly difficult for an employee of the latter to be contented and enthusiastic and to do his best work when he knows that his classmate is making a higher salary.

Advice to the Young Engineer

Some of the criticisms from industry regarding college-trained engineers have been mentioned. The young graduate should study them with profit. The following summary may be of help:

1. Make a special effort to fit in quickly with your fellow workers, remembering that industry places more importance on the ability to get along with fellow employees than it does on technical knowledge and ability.

2. Be ambitious, but do not expect rapid promotion to supervisory positions.

3. Determine whether or not you really have the aptitude for engineering work in industry. If you do not have it, you will probable be happier and make better progress if you are transferred to some other kind of work. An engineering training is a good background for work in many lines.

4. Cultivate the ability to adapt yourself to the routine of operating work without getting into a rut.

5. Show willingness to prepare yourself for advancement, by continued study and reading and by familiarizing yourself with all phases of your company's business.

6. If your company offers the opportunity of working for a period in each of the operating departments as well as in the engineering department, by all means give it your consideration. This method is one of the best to learn the details of a business and to become acquainted in the organization. But bear in mind that how much you will learn is entirely up to you. It will be well for you to outline systematically what information to look for in each department. Keep notes and study them. Study the product of competitors.

7. Do not overestimate the value of your college degree, for it entitles you to nothing. Recognition in industry comes only as a result of accomplishment which is achieved by long hours of hard work. But your college training should give you a tremendous advantage in opportunity to forge ahead.

8. Cultivate the ability to grasp the practical aspects of problems and situations.

9. Cultivate a cost-minded attitude toward all problems that arise in the course of your work. Before making a recommendation, analyze it from the viewpoint of "Will it pay?"

10. Practice report writing. Employers mention a general weakness of young engineers to express themselves effectively orally or in writing.

11. Show enthusiasm and a willingness to work. Be willing to accept responsibility.

12. Cultivate initiative, restrained by reason. Offer to do things without being told. Study processes, machinery, equipment, and product with a view of suggesting improvements, but be careful, in submitting your suggestions, not to raise antagonism.

13. Do not get discouraged.

14. Endeavor to find out from time to time whether your progress is satisfactory to your employer. Invite suggestions as to your weaknesses, so that you can try to improve.

15. Broaden your interests outside of engineering. Although only about 15 per cent of the employers whom I have consulted stress the importance of nonengineering subjects when hiring young engineers, more than 50 per cent of all who answered the questionnaire believe that these subjects are essential to the success of any graduate and will help materially in making progress.

16. Join a professional engineering society; attend its meetings; read its publications. Read technical and trade journals in your line.

Westinghouse Photo

Some Electronic Switching Circuits

By C. C. SHUMARD
MEMBER AIEE

SWITCHING usually is considered as the physical opening or closing of metallic circuits as, for example, where a circuit breaker or a knife switch is put in motion mechanically to break or make connections between conductors leading to a circuit or device. However, switching may be performed in other ways, as by changing the operating potentials from one polarity or magnitude to another polarity or another magnitude. For example, a control voltage on an amplifier tube may be altered to change the circuit from a nonamplifying to an amplifying condition. The making of circuits operative or inoperative by a change in polarity or magnitude, or both, as performed by means of an electronic device is called "electronic switching." No moving parts are involved and the control may be much faster and more economical than control by mechanically operated devices. If two circuits or devices are controlled by an electronic switch, it is called a two-circuit electronic switch.[1,2] In the same way, if three, four, or five circuits are controlled, the electronic switch is called a three-, four-, or five-circuit electronic switch.

Basic Switching Circuits

Although several different types of electronic switches have been devised, this discussion is confined to the type that is considered to be most flexible in its operation. It may control a large number of circuits and, for this reason is called an "*n*-circuit type." The basic circuit of this type of switch employs type-885 gaseous triodes arranged symmetrically so that each tube is made to conduct in a definite order, and in so doing to deionize or stop conduction of the previous tube.[3] As each tube conducts, a voltage drop is produced across a resistor placed in series with the cathode of the tube. This voltage appearing in sequence across each cathode resistor is then, in effect, a switched voltage.

The primary purpose in the derivation of this type of switching circuit was to provide for the observation of several recurrent patterns or wave forms simultaneously on a cathode-ray-tube screen. For this purpose, a suitable amplifying tube is associated with each type-885 tube. Each amplifier tube is controlled by the switched voltage of its gaseous triode and thus is made to operate in sequence with the other amplifier tubes. Although separate input signals are applied to the amplifier tubes, their output currents produce voltage drops consecutively across a load resistor common to all amplifier tubes. The deflecting plates of a cathode-ray tube are connected across the common load resistor and are supplied thus with separate, consecutive voltages from each of the amplifier tubes. In this way, the forms of the voltages supplied to the input circuits of the amplifier tubes can be made to appear apparently simultaneously on the cathode-ray-tube screen. This application, as well as other applications, is discussed after the design factors of the basic voltage-switching circuit have been considered.

Priming

One important requirement for the basic voltage-switching circuit is that to each type-885 tube must be applied a suitable grid-bias voltage, which will determine the specific function of the tube at any particular time as a voltage is switched from one cathode resistor to another. Since symmetrical circuits are used, a description of the cycle of events may be made complete by starting with the steady-state conduction period for one tube and ending

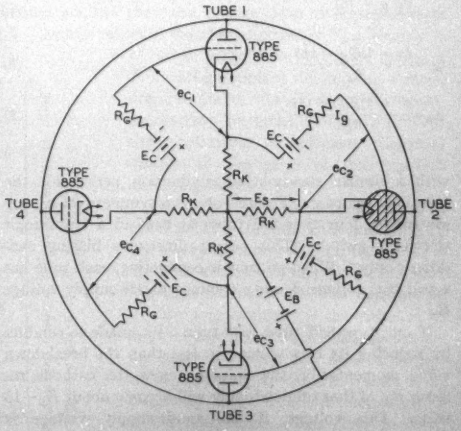

Figure 1. Symmetrical grid-biasing system as used in a four-circuit electronic switch

$e_{c1} = E_c + I_g R_{K1}$ for an unprimed tube
e_{c3} = 0 volts approximately for conducting tube
$e_{c2} = E_c + E_s$ for primed tube
$e_{c4} = +E_c$ for an unprimed nonadjacent tube
Tube 2 conducting

Essentially full text of an address presented before the AIEE New York Section, April 27, 1937. Written especially for ELECTRICAL ENGINEERING.

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The author wishes to thank F. A. Richards for his co-operation, particularly in obtaining the photographs included, and to give acknowledgment to F. H. Shepard, Jr., for the use of his common grid-biasing system which was modified by the author to decrease appreciably the effective switching time.

1. For all numbered references, see list at end of paper.

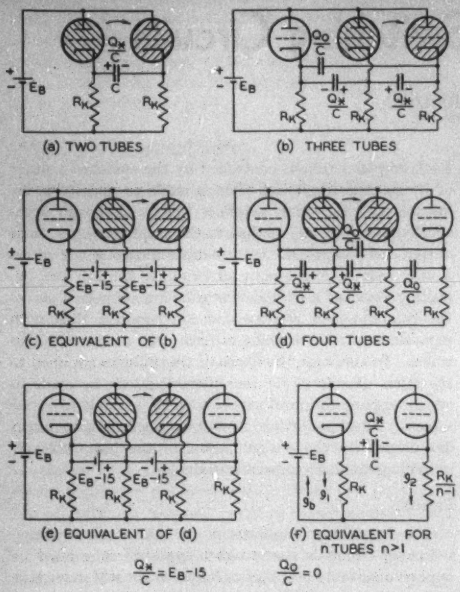


Figure 2. Typical shutoff circuits using two or more tubes

$$\frac{Q_s}{C} = E_B - 15 \qquad \frac{Q_0}{C} = 0$$

Approximate peak currents for diagram (f) after shutoff

$$\mathfrak{g}_1 = \frac{2(E_B - 15)}{R_K} \tag{1}$$

$$\mathfrak{g}_2 = \frac{(n-1)(E_B - 15)}{R_K} \tag{2}$$

$$\mathfrak{g}_b = \frac{(n+1)(E_B - 15)}{R_K} \tag{3}$$

with a similar steady-state conduction period for the tube next in order. Figure 1 shows a symmetrical biasing system for four type-885 tubes as used in a four-circuit electronic switch. This circuit illustrates biasing conditions only. When no tube is conducting, each tube has a grid-bias voltage E_c and a common anode-supply voltage E_B.

If one type-885 tube, say tube 2, is made to conduct by reducing its bias voltage to less than the breakdown value momentarily, the voltage across the cathode resistor R_{K2} of that tube suddenly will become about $E_B - 15$ volts. This voltage, if the anode-supply voltage is constant, will be of substantially constant value, since the drop in a type-885 tube is substantially constant. The voltage $E_B - 15$ constitutes the switched voltage and is designated E_s. Because the voltage E_s is produced in R_{K2}, the bias voltage on tube 3 becomes $E_c - E_s$. The bias voltages on tubes 4 and 1 remain unchanged, if the resistance R_Q is high compared with the resistance R_K, so that the grid current of tube 2 causes negligible voltage drop across R_{K1}. But the grid-bias voltage of tube 3 will be reduced by the magnitude E_s so that the tube will be nearer to the conducting point. Conduction by one tube thus preselects the next tube which is to conduct. This process is called *priming* and the tube so preselected is called a *primed* tube. The other nonconducting tubes are designated *unprimed* tubes. If now a positive impulse voltage of magnitude greater than the difference between the priming bias and the breakdown bias on primed tube 3, but less than the difference between the actual bias and the breakdown bias on tubes 4 and 1, is applied simultaneously to the grids of all type-885 tubes, the primed tube 3 will conduct, while tubes 1 and 4 will not.

A method of biasing all type-885 tubes from a common voltage supply and obtaining priming in a similar manner is discussed later.

Shutoff

When the primed tube is caused to conduct, the previously conducting tube should be shut off simultaneously. In figure 2*a* is shown an elementary shutoff circuit for a two-tube switching circuit in which the cathodes of the two tubes are coupled by the capacitor C. Since shutoff can be made practically independent of the grid-bias voltages once they are properly adjusted, the grid connections are not shown on the circuit. Tube 1 is shown conducting and tube 2 is primed. Before tube 2 is caused to conduct, a steady-state voltage E_s is established across the capacitor C. Tube 2 now may be made to conduct in a very short time compared with the time constant of any external switching circuit that can be employed practically. Capacitor C, however, begins to discharge through the cathode resistor R_K and the two conducting tubes, as soon as tube 2 starts to conduct. As the voltage across R_K and the reverse current through tube 1 increase sufficiently, tube 1 is deionized. If shutoff is assumed to occur instantaneously, two, three, four, or more circuits reduce momentarily to the circuit of figure 2*f* and the peak currents are as shown. For example, the maximum peak current to be supplied by the newly conducting tube is the number of tube circuits plus one, times the steady-state current. This equation is important because the type-885 tube should not be allowed to exceed its peak-current rating.

Shutoff does not occur instantaneously; the smaller the time constants of the cathode coupling circuit, the more capacitor C is discharged before shutoff is effective. These factors limit the maximum number of switching operations per second that may be performed for an allowable switching interval.

Figure 3 shows the calculated transient voltages produced in the cathode resistors of each tube after shutoff of tube 2 for a four-circuit switch. In these calculations it has been assumed that the charges on the capacitors adjacent to the tube to be shut off are not appreciably dissipated before shutoff is complete. These voltages are designated by e_{K1}, e_{K2}, and so on. The voltage across the cathode resistor of tube 3 is the switched voltage E_s, here equal to 100 volts. The ratio of the maximum peak cur-

rents to the steady value is five, since $n = 4$. All voltages vary with time as the algebraic sum of exponential voltages except the switched voltage, which is substantially constant. For these curves $C = 0.002$ microfarad and $R_K = 5{,}000$ ohms.

Figure 4 shows oscillograms of the superimposed transient voltages e_K occurring respectively across the cathode resistors of two-, three-, and four-circuit electronic switches for a switching or impulse frequency of 5,000 cycles per second. The horizontal sweep frequency also is 5,000 cycles per second. The values of $C = 0.002$ microfarad, $R_K = 5{,}000$ ohms, and $E_s = 100$ volts are the same as for figure 5, which shows similar transient voltages for a seven-circuit switch. In figure 5*a* the transients are superimposed, but in figure 5*b*, they are shown in consecutive order. The horizontal sweep frequency in figure 5*b* is one-seventh of the switching or impulse frequency in figure 5*a*.

A comparison of actual and calculated transient values of e_K shows a reasonably close correspondence for these C and R_K values, which are fairly low. Evidently the correspondence is least for the condition $n = 2$, where the actual time constant is lowest and the loss of capacitor charge greatest. The actual initial values, as would be expected, are not as high as the calculated values indicate, but the full maxima do not appear on the photographs, partly because some time is required for the sweep return.

All transient curves show that the switched voltage E_s is substantially constant but that the transient voltages e_K decrease to zero at different rates. For each value of n the voltage e_K of the longest positive duration is the one for the tube which has just been shut off. A rise of about 20 per cent in effective plate voltage may occur on the second tube preceding the conducting tube for values of n greater than two.

Impulse Voltage Considerations for Triggering

The character of the impulse voltage required to break down or trigger consecutively each tube of the basic voltage-switching circuit also requires consideration. The impulse voltage should be of steep wave front; a voltage of sinusoidal wave form is not suitable. The impulse voltage across the series plate resistance R_t of the usual sweep circuit at the time of discharge of the sweep-circuit capacitor generally has been found to serve satisfactorily. Such a voltage is of approximately exponential form. Some slight modifications of the sweep circuit ordinarily are necessary because the impulse voltage should be positive with respect to ground. Figures 6 and 7 show the essentials of the usual sweep circuits employing a current-limiting tube and current-limiting resistance, respectively. Figures 6*a* and 7*a* show the modifications necessary for using these circuits as positive-impulse sources.

The ordinary sweep-discharge voltage e_t obtained by connecting across the relatively low impedance R_t, usually is of sufficient amplitude, is synchronized with the sweep automatically, is of very short duration, and may be synchronized readily to a suitable reference voltage. The value of R_t usually is fixed at some value of from 500 to 1,000 ohms. This resistor may be used as a potentiometer for adjustment of the impulse voltage, or an auxiliary voltage divider may be employed. If the latter is used, its resistance should be kept low to avoid impulse attenuation, particularly at high switching frequencies. Its resistance, however, should not be low enough to reduce the effective value of R_t much below 500 ohms.

The amplitude of the impulse voltage e_t is only slightly less than the sweep-capacitor voltage at sweep-tube breakdown less the tube voltage drop of approximately 15. At low values of switching frequency F_t, e_t usually is of ample magnitude. At high values of F_t the attenuation of the impulse voltage attributable to circuit and grid capacitances may be great enough to prevent the application of sufficient triggering voltage to the grids of the type-885 switching tubes.

The duration of the impulse depends essentially on the time constants $R_t C_t$ of the sweep-discharge circuit, where C_t is the selected value of the sweep capacitors C_{t1}, C_{t2}, etcetera. The time constant $R_t C_t$ therefore is altered if the value of C_t or R_t is changed. Such changes usually are made to obtain the desired sweep-frequency ranges and the values of C_t ordinarily range from 1.0 microfarad to 0.0005 microfarad. This gives an $R_t C_t$ range from 500 microseconds to 0.25 microsecond for an R_t value of 500 ohms. The value of $R_t C_t$ should not be large compared with the time constants of some of the switching circuits as explained later. However, the $R_t C_t$ range ordinarily used is satisfactory.

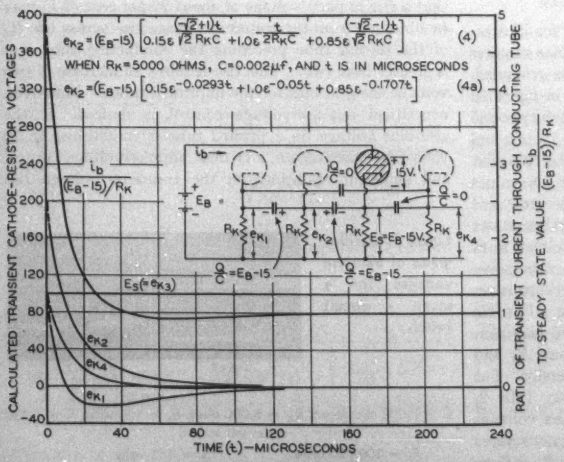


Figure 3. Curves of calculated transient voltages produced in the cathode resistors of each tube after shutoff of tube 2 for a four-circuit switch

Figure 4. Oscillograms of superimposed transient voltages across the cathode resistors of two-, three-, and four-circuit electronic switches for an impulse frequency of 5,000 cycles per second

C = 0.002 microfarad, R_K = 5,000 ohms, E_s = 100 volts, F_i = 5,000 cycles per second

R_1 = 100,000 ohms	E_B = 115 volts
R_2 = 50,000 ohms	E_C = −105 volts
R_g = 150,000 ohms	$e_{i\,min}$ = 50 peak volts
R_f = 30,000 ohms	c_i = 100 micromicrofarads

If modification of the auxiliary sweep is desirable, a second simple sweep circuit may be constructed to meet the requirements, and may be made a part of the switch circuit itself. Thus, since linearity is no object, suitable circuit constants may be chosen and higher impulse output may be obtained by increasing the bias voltage on the second auxiliary sweep tube. This sweep voltage is synchronized to the same reference voltage as the usual sweep voltage so that the two return times coincide.

The use of the impulse voltage is closely related to the method of obtaining the grid bias for the type-885 tubes. Since a common voltage supply for the grid bias generally is used, it is considered desirable to describe first this biasing method and then show how the impulse voltage is applied.

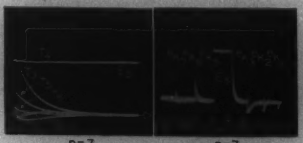
Grid Biasing From a Common Voltage Supply

Separate grid bias may be used, as shown for illustration purposes in figure 1, but common grid bias requires only one source of bias voltage, which can be grounded. This common grid-biasing method is shown in figure 8*a* where the grid bias is applied to the grid of each type-885 tube by means of the voltage-divider circuits R_K, R_1, and R_2 from the bias-supply voltage E_c. From the transient standpoint, it will be usually desirable to keep the values of $R_K C$, and hence R_K, small but R_1 and R_2 may or may not be large compared with R_K depending on whether or not it is desired to have a substantial negative voltage from cathode to ground for a nonconducting tube. A negative voltage may be desirable (as shown later) because it reduces the effective transient times of switching. For this reason, it is preferable to compute the general bias conditions; from these, the conditions for which R_1 and R_2 are large compared to R_K may be obtained easily. For the steady-state condition with one tube, say tube 2, conducting, the resistance network for the bias voltages of four or n tubes becomes a simple equivalent network as progressively shown in figure 8. The resistance $R_g = R_g + R_f$ is made large compared with R_K in order to limit grid current to a small value relative to the plate current, so that the drop through the cathode resistor of tube 1 caused by the grid current of tube 2 may be assumed to be negligible. Because the grid potential of a conducting tube is very closely the same as its cathode potential, the grid of this tube is shown connected to its cathode. The grid bias on the primed tube is indicated as e_c'; all other tubes, being unprimed tubes, have the bias shown as e_c. As stated previously, the capacitors C_i shown in figure 8*a* are used for impulse coupling.

In figure 9 are shown the current and voltage relations for the general case, with R_1 and R_2 of the same order as R_K, and for the special case in which R_K may be neglected in comparison with R_1 and R_2. Again, of course, e_c is the bias on unprimed tubes and e_c' the bias on the primed tube; e_d is the difference in bias between unprimed tubes and the primed tube. These voltages may then be computed in terms of the desired switched voltage E_s from a consideration of normal breakdown grid voltages and the transient voltages.

Figure 10 illustrates the selection of the operating voltages. Here the voltages e_c, e_c', and e_d are plotted in terms of E_s, the desired switched voltage, for a ratio of $R_1 = 2\,R_2$, or $a = 2$, where R_1 and R_2 are assumed to be large compared with R_K. The line e_c'' gives the approximate grid-bias voltage at which any nonconducting type-885 tube will become conducting. This voltage is equal to the plate voltage divided by the grid-control factor E_B/μ, or in terms of the switched voltage E_s and grid-control factor of ten, $e_c'' = (E_s + 15)/10$ volts. The lines marked E_c = 180, 165, etcetera, terminating on the breakdown voltage line, provide data for the determination of the bias voltages on the primed and unprimed tubes. For example, suppose the switched voltage desired is 100 volts. Then the breakdown voltage is (100 + 15)/10 or 11.5 volts. The E_c grid-bias line that just gives this value is the one on which E_c is 67.5 volts. However, the reader will recall that a rise in plate voltage of about 20 per cent of E_s may be obtained from the transient voltage rise across the R_K of the second tube preceding the conducting tube if n is greater than two. This rise requires an increase of two volts in the grid bias for the unprimed tubes. Moreover, noncritical impulse-voltage control is desired. If the grid-bias voltage on a primed tube is established at 20 volts from breakdown, a critical impulse-voltage control and sufficient allowance for the transient voltage rise

Figure 5. Oscillograms of transient voltages for a seven-circuit switch



C = 0.002 microfarad, R_K = 5,000 ohms, E_s = 100 volts, F_i = 5,000 cycles per second

R_1 = 100,000 ohms	E_B = 115 volts
R_2 = 50,000 ohms	E_C = −105 volts
R_g = 150,000 ohms	$e_{i\,min}$ = 50 peak volts
R_f = 30,000 ohms	c_i = 100 micromicrofarads

are provided. The values of grid-bias voltage for primed tubes given by the line 20 volts from breakdown ordinarily will be feasible for intermediate values of desired switched voltages around 100 volts. The intersection of the ordinate at $E_s = 100$ volts and the line $e_c' = (20 + e_c'')$ volts gives an E_c of about 96 volts, an unprimed-tube grid bias of 64 volts, and a primed-tube bias of 32 volts. The line e_d giving the difference in bias between an unprimed tube and the primed tube shows this to be about 32 volts as indicated by the difference 64–32 = 32 volts. This condition also allows sufficient margin so that the impulse voltage need not be critically adjusted. If e_d is not considered to be sufficient for the desired E_s value, a lower ratio between R_1 and R_2 should be used. For higher values of E_s, a higher ratio could be used. From similar lines or simple calculations the operating voltages may be determined for any case. When the method is understood, it will be found simpler and faster to compute the values directly, particularly if R_K is intended to be about the same size as R_1 and R_2. Examples of such calculations are given later.

Figure 11 shows some oscillograms of biasing conditions at a low-switching frequency $F_t = 88$ cycles per second. Figure 11*a* shows grid voltages to ground of all tubes and figure 11*b* the voltage at $R_1 - R_2$ midtap to ground. The high relative voltage drop across the grid resistance R_g of the conducting tube 2, as well as the relatively small influence of this conduction on the bias levels for primed and unprimed tubes, is indicated.

Triggering

With reference again now to the application of impulse voltage to the circuit of figure 8*a* the reader will see that the impulse voltage e_t is applied effectively from the grid of each type-885 tube to ground. Since R_g usually is large relative to R_K, the impulse voltage must have a peak value equal at least to the voltage by which the grid-bias voltage on the primed tube exceeds its breakdown voltage. The capacitor C_t should have a value of about 100 micromicrofarads or less for usual R_g values of about 200,000 ohms. Small values of C_t serve to steepen the impulse wave form and to keep the time constants of the grid circuits low. The resistances R_j are inserted (1) to keep the grid circuit of a conducting tube from appreciably decreasing the impulse terminating impedance, (2) to keep the grid impedance to ground as high as feasible with respect to R_K, and (3) to limit the initial peak grid current of a conducting tube to about one milliampere. The value of R_j depends also on the grid voltage at breakdown and series current-limiting resistances other than R_j. For example, if the grid voltage at breakdown is 11.5, R_j should have a minimum value of 11,500 ohms. The resistance R_g serves for impulse coupling and to keep the grid current small. Its value is not critical. Values of from 50,000 to 300,000 ohms are suitable.

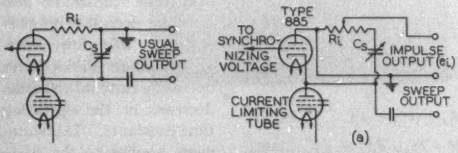


Figure 6. Essentials of a sweep circuit employing a current-limiting tube

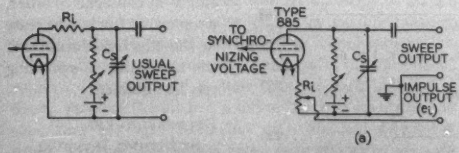


Figure 7. Essentials of a sweep circuit employing a current limiting resistor

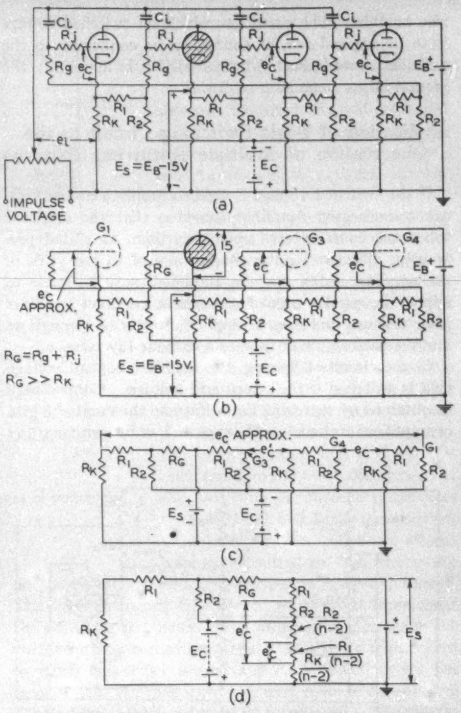


Figure 8. Equivalent circuits of the method used for supplying grid-bias voltage to several type-885 switching tubes from a common voltage supply

Basic Voltage-Switching Circuit

Figure 12 shows the complete basic voltage-switching circuit. It is drawn for five switching circuits, but it is a symmetrical arrangement and may be contracted to four, three, or two switching circuits or extended to an indefi-

nite number. The circuits to which the switched voltage is to be applied are, of course, to be connected to the cathode points indicated by the arrows in figure 12; the ground forms a common return.

Application of Basic Switching Circuit to the Observation of Multiple Recurrent Patterns

If the switched voltage is used to supply a control voltage to successive amplifier tubes so that the amplifier tubes are consecutively operative, then, as stated previously, different input voltages applied to the grids of the amplifier tubes may be amplified, may be made to appear in regular sequence across a common amplifier plate resistor, and may be applied directly or through an intermediate amplifier tube to a cathode-ray tube.

In the circuits following, the amplifier control voltage that is switched is the screen-grid voltage. Control may be obtained by switching the voltage on the number 3 grid of amplifier tubes such as the type $6L7$, or by switching any other control-grid voltage on any suitable amplifier tube from cutoff to a normal value. Control-grid switching may be advantageous in some cases but is considered to be less flexible and less easily controlled.

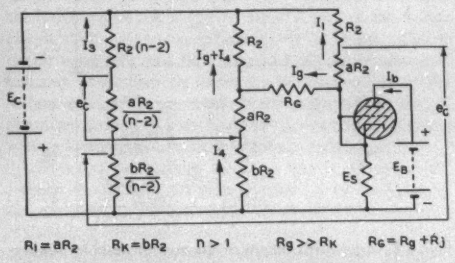


Figure 9. Diagram showing the steady-state current and voltage relations in an electronic switching circuit

For reference, one arrangement of a four-circuit electronic switch with auxiliary apparatus for obtaining four simultaneous wave-form patterns on a cathode-ray tube is shown in figure 13. Here are illustrated the voltage-switching circuit, the combination impulse sweep and the usual sweep circuit, the voltage supply, the amplifier tubes, and a delay switch. In this circuit, and in the circuit of figure 17, the reader should note that (1) the number of switching circuits may be altered, (2) the impulsing circuits may be any one of the types shown, (3) any suitable amplifier-tube arrangement may be used, (4) the voltage supplies are conventional, and (5) any suitable operating voltages may be used.

As its designation implies, the *delay* switch, in moving from "off" position 1 to the operating position 3, delays the application of the triggering voltage to the electronic switch until the electronic switch has the proper operating conditions. In position 1 temporary overpriming of one type-885 tube is provided to insure that it alone will become conducting as position 2 is reached and the plate voltage is applied to the overprimed tube; between positions 2 and 3 the overpriming is removed, the operating voltages are then correct, and the triggering voltage may be applied in position 3. The voltage appearing across the cathode resistor of each type-885 tube is supplied as a screen voltage to its associated amplifier tube; consequently, these transient voltages constitute screen voltages for the time they persist. Their effect, then, should be made as short in duration as is feasible. The time constants of the switch proper should be kept as low as is practical. To obtain time constants less than 10×10^{-6} second, however, requires that the steady-state plate currents be reduced so that fewer positive ions need be removed. The grid time constants also must be decreased proportionally. Using lower operating voltages allows lower operating currents and some decrease in the operating time constants. This statement applies to the basic electronic switch. Yet if such a switch is used to operate amplifier tubes singly in consecutive order, a somewhat further decrease in the effective duration of the transients of switching can be obtained.

General Case ($E_K \neq 0$)

$$e_c = aE_c/(1+a+b) \quad (5)$$

$$e_c' = E_c\left[\frac{a^2+a-b}{(1+a)(1+a+b)}\right] + \frac{E_s}{1+a} \quad (6)$$

$$e_d = e_c - e_c' = \frac{1}{1+a}\left[E_s - \frac{bE_c}{1+a+b}\right] \quad (7)$$

$$e_c = (a/b)E_k \quad (8)$$

$$E_c = [(1+a+b)/b]E_k \quad (9)$$

$$e_c' = \frac{1}{1+a}\left[E_k\left(\frac{a^2+a-b}{b}\right) + E_s\right] \quad (10)$$

$$e_d = [1/(1+a)](E_s - E_k) \quad (11)$$

$$a = (E_s - E_k - e_d)/e_d \quad (12)$$

$$b = \frac{aE_k(1+a)}{e_c'(1+a) + E_k - E_s} \quad (13)$$

$$R_K' = [(1+a)R_k]/(1+a+b) \quad (14)$$

$$R_k = [(1+a+b)R_K']/[b(1+a)] \quad (15)$$

$$I_b = [E_s(1+a+b) - bE_c]/[R_k(1+a)] \quad (16)$$

$$R_G = \frac{(1+a+b)E_s - (a+b)(E_c + I_gR_k)}{(1+a+b)I_g} \quad (17)$$

$$R_s = \frac{R_k(a+b)\left[\frac{bE_c}{1+a+b} - 0.1(E_s+15)\right]}{aE_c + 0.1(E_s+15)(1+a+b)} \quad (18)$$

Special Case ($E_K = 0$, that is, E_K is substantially equal to zero, or $b << 1$ or a)

$$e_c = aE_c/(1+a) \quad (19)$$

$$e_c' = (aE_c + E_s)/(1+a) \quad (20)$$

$$e_d = E_s/(1+a) \quad (21)$$

$$I_b = \frac{E_s - E_c}{R_k(1+a)} + \frac{E_s}{R_K} \quad (22)$$

$$R_G = \frac{(1+a)E_s - a(E_c + I_gR_k)}{(1+a)I_g} \quad (23)$$

$$R_s = -\frac{0.1aR_k(E_s+15)}{aE_c + 0.1(E_s+15)(1+a)} \quad (24)$$

Decreasing the Switching Interval

As the screen-grid (or other control-electrode) voltages

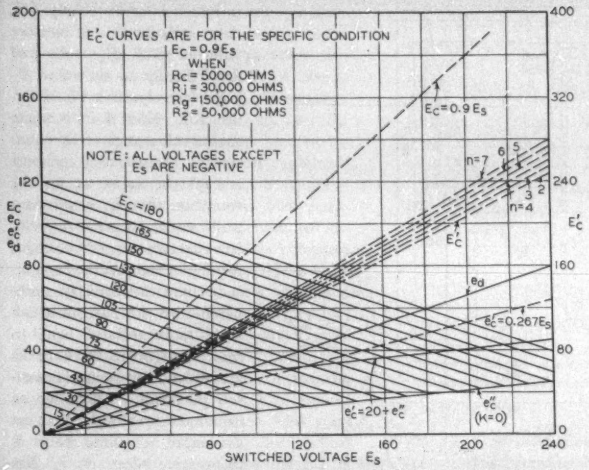


Figure 10. Curves used for the selection of the operating voltages of switching circuits

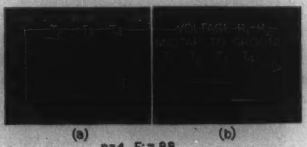
of the amplifier tubes are switched, two methods can be used to decrease the apparent duration of the transients. The first is to take full advantage of the fact that the transconductance g_m of sharp-cutoff multielectrode tubes drops rapidly with decrease in screen voltage. For example, the transconductance of type-6J7 tubes, which were used as the switched amplifier tubes in the circuits shown, ordinarily drops to one per cent or less for the usual unidirectional operating voltages (plate voltage $E_p = 250$, suppressor voltage $E_{c_3} = 0$, and control-grid voltage $E_{c_1} = -3$) as the screen-grid voltage E_{c_2} drops from +100 to +20 volts. For each condition of the circuits used, the transconductance drops to one per cent or less as the transient screen voltage e_{c_2} drops to 20 per cent of the steady-state value E_{c_2}. For switched screen voltages, the E_{c_2} value becomes the switched positive voltage E_s and the transient values are the various e_K values. Figures 4 and 5 show that for each value of n the e_K value of the longest positive duration identifies the tube that has just been shut off. For nonconducting tubes, however, the values of e_K drop almost to zero, or the steady-state voltages E_K across the cathode resistors are almost zero. The voltages E_K constitute the steady-state screen-grid voltages of the presumably inoperative amplifier tubes. These voltages are approximately zero for this first method of reducing the apparent transient time of switching and are made somewhat negative for the second method. This difference is used to distinguish between the two methods.

The amplifier switching circuit of figure 13 is an illustration of the circuit in which E_K is substantially equal to zero. Figure 14 shows four oscillograms taken with this circuit. For each, three wave-form patterns were obtained using three of the amplifiers; the fourth amplifier with no input signal was used for the zero line. For (*a*), (*b*), and (*c*) of this figure, the time constants of the basic switching circuit were the same, that is $C = 0.004$ microfarad and $R_K = 5{,}000$ ohms, but the switching or impulse frequencies were 200, 400, and 1,000 impulses per second, respectively. The two sweeps were synchronized so that the sweep frequency and the switching frequency F_t were the same. The signal frequency F_s, however, was kept at three times the switching frequency. The progressive increase in the switching time is readily noticed. In (*d*) F_t was increased to 5,000 cycles per second and F_s to 15,000 cycles per second, but the time constants were reduced by reducing C from 0.004 microfarad to 0.002 microfarad. The switching time then was about 20 per cent of a sweep cycle.

The values for biasing resistors of the amplifier switch of figure 13 have been computed by using the equations of figure 9 for the specific case in which $R_1 = 2R_2$ and R_1 and R_2 are large compared with R_K. A switched voltage E_s of 100 volts is desired so that the screen grids of the 6J7 tubes could be operated at this value. The other basic switching-circuit potentials are selected as previously described.

The second method of decreasing the apparent persistence of the transient of longest duration is to apply a

Figure 11. Oscillograms of grid-bias voltages at a switching frequency of 88 cycles per second



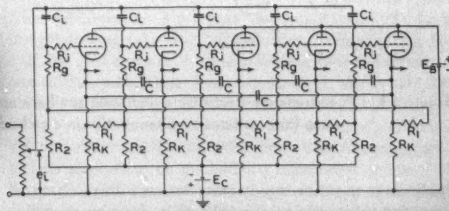
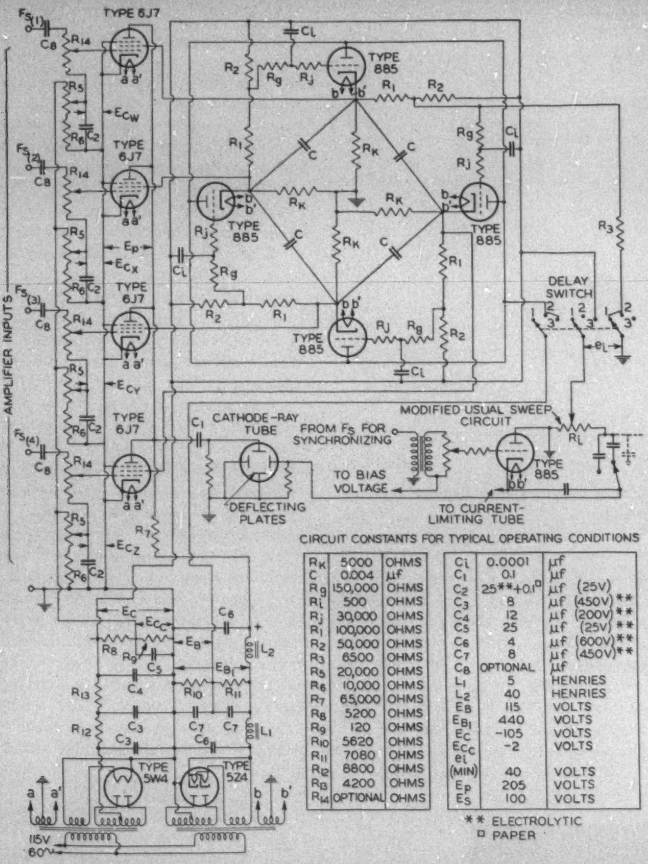


Figure 12. Diagram of a complete basic voltage-switching circuit



R_K	5000	OHMS
C	0.004	μf
R_g	150,000	OHMS
R_1	500	OHMS
R_j	30,000	OHMS
R_1	100,000	OHMS
R_2	50,000	OHMS
R_3	6500	OHMS
R_5	20,000	OHMS
R_6	10,000	OHMS
R_7	65,000	OHMS
R_8	5200	OHMS
R_9	120	OHMS
R_{10}	5620	OHMS
R_{11}	7080	OHMS
R_{12}	8800	OHMS
R_{13}	4200	OHMS
R_M	OPTIONAL	OHMS

C_1	0.0001	μf
C_1	0.1	μf
C_2	25**+0.1□	μf (25V)
C_3	8	μf (450V)**
C_4	12	μf (200V)**
C_5	25	μf (25V)**
C_6	4	μf (600V)**
C_7	8	μf (450V)**
C_8	OPTIONAL	μf
L_1	5	HENRIES
L_2	40	HENRIES
E_B	115	VOLTS
E_{B1}	440	VOLTS
E_C	−105	VOLTS
E_{CC}	−2	VOLTS
e_L (MIN)	40	VOLTS
E_P	205	VOLTS
E_S	100	VOLTS

Figure 13. A four-circuit electronic switch with auxiliary apparatus for obtaining four wave-form patterns simultaneously on a cathode-ray tube

fairly large negative steady-state screen voltage E_K to all amplifier tubes, except the tube that is to be operative with E_c as its screen voltage. If this is done, the time is decreased so that each supposedly inoperative amplifier tube becomes actually inoperative after the instant of triggering. The important point is that this quicker action is obtained without change in the equivalent electronic-switch R_KC product. It is done by making the biasing resistors R_2 and R_1 for common grid bias of the same order as R_K. To illustrate the method, the transient voltage appearing across the cathode resistor of the tube that is not operating has been recomputed for a two-tube switch in which R_2 and R_1 are not of sufficiently high values to be neglected in comparison with R_K. The transient voltage e_K from cathode to ground of inoperative tube 1, in which interest chiefly lies, rises initially to a positive value of $(2\ E_c - E_K)$ volts and drops finally to the value E_K volts (see equation 25 of figure 15). Now if R_2 is made such a value, as given by equation 15, that the time constant is kept the same as for the condition that E_K is substantially equal to zero, the relative effective transient voltages for E_K of substantial magnitude may be directly compared with the case in which E_K is substantially equal to zero. In figure15, three curves are drawn for such comparison purposes. Assuming as explained previously that an associated amplifier tube is inoperative when its e_K has dropped to 20 volts, it will be seen from curves A, B, and C that e_K reaches 20 volts when t is 23, 15, and 12.5 microseconds, respectively. Conditions for curve B, for example, give a resultant decrease in effective transient time of about 30 per cent from the conditions of curve A. The decrease is even greater for the actual circuits, since the peak values do not reach the computed values.

The method is illustrated further by the oscillograms of figure 16 for a three-circuit switch. E_K for the same three-circuit switch of figure 4*a* was almost zero. For (*a*) and (*b*) of figure 16, changes were made in the switching-circuit constants R_2, R_1, and R_K to provide for a fairly large value of E_K. R_2 was changed from 50,000 to 10,000 ohms, R_1 was changed from 100,000 to 200,000 ohms, and R_K from 5,000 to 6,000 ohms, so that the effective cathode resistance R_K' remained the same at 5,000 ohms. In (*a*), E_c was made −132 volts and in (*b*), −264 volts. The respective values of E_K were then −22 and −44 volts. The transient times when $e_K = 20$ volts for tube 2 for each of the conditions $E_K \doteq 0$, $E_K = -22$, and $E_K = -44$ volts are found from figure 15 to be approximately 17, 8, and 5 per cent, respectively; therefore, (*b*) of figure 16 shows a decrease of about 70 per cent in transient time from the condition where $E_K \doteq 0$. Further decrease may be obtained by increasing E_K but the advantage is not proportionally as great. This same method is, of course, applicable to any number of circuits. It is designated by

the condition $E_K \neq 0$. The example illustrates the only major modification necessary to change from switch operation with $E_K \doteq 0$ to operation with $E_K \neq 0$. A change in the E_c value and supply may be necessary.

For chosen values of E_s, e_c', e_d, and E_d, the values of a and b may be selected by drawing bias lines as previously explained, but they may also be determined quickly and accurately by using the bias equations. Examples of such calculations are given later in conjunction with the complete diagram of the three-circuit amplifier-switch of figure 17 for which two sets of typical switching-circuit conditions are given.

For the first set it has been assumed that a switched voltage E_s of 100 volts and an acritical operational margin for impulse adjustment is desired and that a maximum negative screen voltage E_K of -40 volts is to be used. Acritical impulse control will be obtained if the priming bias e_c' is kept 20 volts from the breakdown bias e_c''. Since e_c'' is given by $(E_s + 15) / \mu$, which is equal to $(100 + 15)/10$, or 11.5 volts in this instance, e_c' should be -31.5 volts. Suppose also that the difference in bias, $e_d = e_c - e_c'$, between the unprimed tube and the tube is made -40 volts. Having the values $E_s = 100$ volts, $E_K = -40$ volts, $e_c' = -31.5$ volts and $e_d = -40$ volts, it follows that the value of a obtained from equation 12 of figure 9 is 2.5. When this value of a is substituted in equation 13 of figure 9, the value of $b = 1.4$ is obtained. The value of E_c then is -140 volts, from equation 9 of figure 9.

The actual value of R_K' the equivalent cathode resistance, is not critical but should be chosen so that the $R_K'C$ product is not much less than ten for R_K' in ohms and C in microfarads. However, because R_K' constitutes the impedance of the amplifier screen grid to its cathode, R_K' should be kept well below 50,000 ohms in value. The lower limit of R_K' will be set by the peak plate current of a type-885 tube at breakdown, but a value somewhat larger usually is desirable for two reasons: (1) shutoff will be faster with lower plate current, and (2) regulation of the bias supply generally used for E_c need not be as good as is required for a lower value of R_K'. If R_K' is made 5,000 ohms, then from equation 15 of figure 9, $R_3 = 5{,}000$ ohms, and since $R_1 = aR_2$ and $R_K = bR_2$, $R_1 = 12{,}500$ ohms, and $R_K = 7{,}000$ ohms. The steady-state plate current through the conducting tube is 28 milliamperes, from equation 16.

If the grid current of the conducting tube is limited to one milliampere, then, from equation 17, R_g is 207,000 ohms. Since R_j should be at least equal to 1,000 $[(E_s + 15)/\mu] = 1{,}000\ (115/10) = 11{,}500$ ohms, R_s is made 200,000 ohms and R_j, 15,000 ohms. The foregoing conditions allow C to be made 0.002 microfarad or less. It is given as 0.002 microfarad in the first set of conditions.

The second set of switching conditions for figure 17 gives an example of further reduction in the apparent switching interval. A lower switched voltage, closer biasing differentials between primed and unprimed tubes, and a relatively higher steady-state negative voltage E_K across R_K are used. The lower switched voltage and the closer bias differences allow lower actual time constants, and the relatively higher E_K value or the greater ratio of E_K to E_s gives the apparent reduction in time constants. Operation with smaller biasing differentials requires good regulation of all voltage supplies and close control of the impulse voltage. The time constants of the grid circuits should also be kept as low as, or lower than, the plate-current time constants.

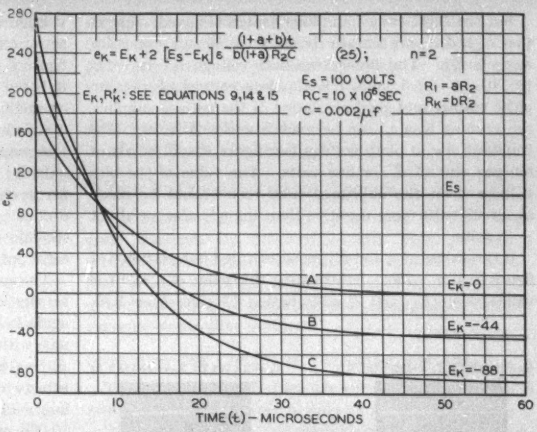


Figure 15. Curves of transient voltage from cathode to ground versus time, showing the variation with magnitude of E_K

A—$e_K = 200\varepsilon^{-0.1t}$ $1,a>>b$ $R_K = 5{,}000$ ohms

B—$e_K = -44 + 288\,\varepsilon^{-0.1t}$ $a = 2, b = 0.6$, $E_C = -264$ volts, $R_3 = 6{,}000$ ohms, $R_K' = 5{,}000$ ohms

C—$e_K = -88 + 376\varepsilon^{-0.1t}$ $a = 2, b = 0.6$, $E_C = -528$ volts, $R_3 = 6{,}000$ ohms, $R_K = 5{,}000$ ohms

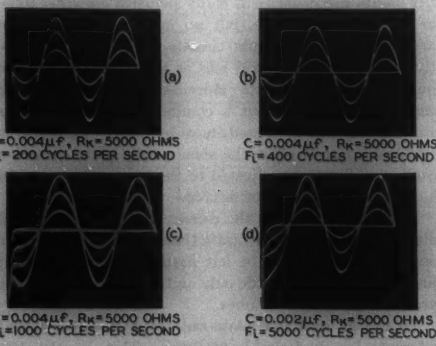


Figure 14. Oscillograms taken with the circuit of figure 13

For the three-circuit amplifier switch assumed, suppose that E_s and E_K are tentatively chosen as 50 and -35 volts, respectively. The breakdown-bias voltage e_c'' is $-(E_s - 15)/10$, or -6.5 volts. With close control of the impulse voltage and good regulation of the voltage supplies, the priming bias e_c' can be made about -20 volts. The transient rise in plate voltage (see figure 4) will be about ten per cent of E_s, or five volts. The value of the bias voltage e_c on the unprimed tube then should be made about 25 volts more negative than the e_c' value, or about -45 volts.

If the values of e_c and E_K are substituted in equation 8 of figure 9, $a = 1.28b$. Substituting this value of a and the values of e_c' E_K, and E_s in equation 13 gives $b = 1.89$.

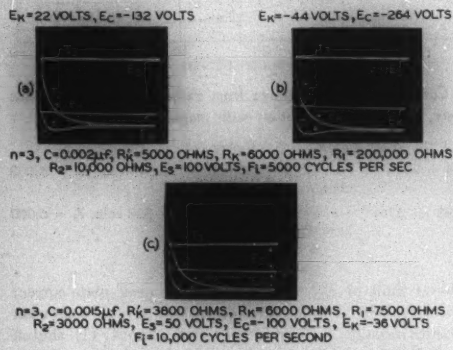

EK=22 VOLTS, EC=-132 VOLTS
EK=-44 VOLTS, EC=-264 VOLTS
(a)
(b)
n=3, C=0.002μf, R'K=5000 OHMS, RK=6000 OHMS, R1=200,000 OHMS
R2=10,000 OHMS, Es=100 VOLTS, Fi=5000 CYCLES PER SEC
(c)
n=3, C=0.0015μf, R'K=3800 OHMS, RK=6000 OHMS, R1=7500 OHMS
R2=3000 OHMS, Es=50 VOLTS, EC=-100 VOLTS, EK=-36 VOLTS
Fi=10,000 CYCLES PER SECOND

Figure 16. Oscillograms for a three-circuit switch, demonstrating the effect computed for figure 15

Hence, $a = 2.42$. If for convenience, however, a is made 2.5 and b is made two, then the values $E_K = -36$, $e_c' = -20.7$ and $e_c = -45.1$ volts satisfy the conditions for $E_s = 50$ volts. These values closely approximate the desired values. Arbitrarily choosing a compromise value of 3,800 ohms for R_K' to obtain an R_K value of 6,000 ohms, makes $R_3 = 3{,}000$ ohms, and $R_1 = 7{,}500$ ohms. The steady-state plate current I_b is, from equation 16, 22.6 milliamperes. For a conducting-tube steady-state grid current of one milliampere, the series grid resistance $R_g = R_g + R_f$ becomes, from equation 17 of figure 10, 129,000 ohms. R_f should have a minimum value of 1,000 $e_c'' = 6{,}500$ ohms, and for convenience, R_g is made 120,000 ohms. The coupling capacitors C_i are 30 micromicrofarads to provide grid-circuit time constants lower than those of the cathode circuits. With this value of C_i the minimum peak value of triggering impulse voltage applied becomes 80 volts. The value of C may not be reduced much below $C = 0.0015$ microfarad for stable operation. Hence, this value of C is used. The $R_K' C$ value, therefore, is 5.7 with C in microfarads and R in ohms. For R_3, which is connected momentarily in the switching circuit proper to cause only one tube to break down just before the triggering voltage is applied, the maximum value allowable for any set of conditions may be calculated from equation 18 of figure 9. The maximum allowable value of R_3, however, is based on having either battery supplies for E_s and E_c, or rectified supplies with perfect regulation. For usual rectified-alternating-voltage sources, R_3 may be made somewhat larger than the value obtained from equation 18.

In (*c*) of figure 16 are shown the transient voltages e_K across the cathode resistors R_K for the second set of conditions for an impulse frequency F_i of 10,000 cycles per second. The longest effective transient time is about eight per cent of a sweep cycle.

The application of this complete switch-amplifier system to the simultaneous observation of recurrent patterns again is illustrated by figure 18. Here out-of-phase signals with a frequency of 10,000 cycles per second ($F_{s1} = F_{s2} = 10{,}000$) are applied to the inputs of two amplifier tubes while the third amplifier is used for the zero reference line. The impulse or switching frequency F_i also is 10,000 cycles per second. The pattern or picture frequency F_p is, of course, $10{,}000/3 = 3{,}333$ cycles per second; that is, each of these patterns appeared 3,333 times per second. The switching conditions are those of case 2 (figure 17), except that the amplifier plate loads are 20,000 instead of 10,000 ohms as shown in the figure. For the 20,000-ohm plate loads, the effective switching time is about twice as large as is indicated in (*c*) of figure 16, because the amplifiers shown in figure 18 did not pass all of the highest switching frequencies.

Amplifiers Used With Electronic Switches

Although the amplifier design required for electronic switches is conventional except for the possible use of a peaking coil, the operating conditions are somewhat unusual. The amplifier should be designed to pass the higher-frequency components of the switched voltage to the screen grid. Greater amplifier gain can be obtained, if desired, with additional amplifier stages. Push-pull amplifier output may be obtained by ordinary single-ended to push-pull transformation methods. Push-pull switched amplifier circuits are feasible for balanced amplifier inputs also. Twice as many switched amplifier tubes, are required, of course, but no more switching circuits are necessary. The input circuits must be isolated effectively with regard to grid bias as well as to the different input signals. Separate individual bias controls are employed, therefore, but a common fixed rectified bias source, properly by-passed, may be used. The separate grid-bias controls allow the steady-state plate current of each amplifier to be adjusted to the same value provided a d-c reference line is not desired.

In order to maintain the correct amplifier voltage conditions after the initial bias adjustment has been made, one bias value should be left fixed, and subsequent adjustments should be made only on the bias potentiometers provided for the other tubes.

To use at least one plate voltage as a direct-voltage reference line is desirable at times. This may be done by adjustment of the bias of one or more amplifier tubes

without input signal. Any amplifier without input signal can, of course, be used as a zero reference line. For each reference line desired, an additional switching circuit should be provided.

The amplifiers require that one side of a signal-input circuit be grounded. The wave form of the potentials of any circuit points to ground may be easily observed. The wave forms of currents through isolated circuits may have to be obtained by the use of transformers, or by analysis of component wave forms.

No filtering of the switched screen voltage is necessary or desirable. It should not be attempted unless the effect on the switching is considered. The supplied screen voltage is kept constant inherently, except during the switching transient time, by the regulation of the switch itself.

The amplifier arrangement of the three-circuit switch of figure 17 shows a method of using two stages to obtain relatively higher gain and output voltage. Such an amplifier is suitable for lower-frequency switching. The first stage, operating at relatively low plate voltage and gain, actuates a second stage operating at higher plate voltage and additional amplification.

Additional Applications of the Basic Switching Circuit

Switching Common Ground Circuits

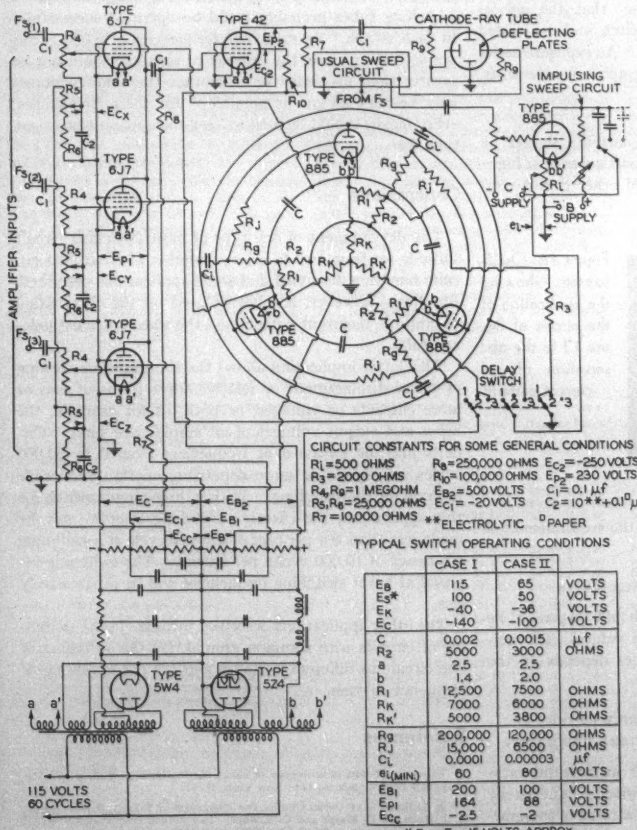
The basic switching circuit can be used directly to operate consecutively different circuits with a common ground. As examples, relays may be actuated up to the limit of their operating frequency and separate amplifiers or oscillators may be turned off or on effectively by switching some controlling voltage.

Switching One Circuit to Different Voltages

Where amplifier tubes are associated with the type-885 switching tubes, as for viewing multiple patterns on a cathode-ray tube, the amplifier tubes may be used to supply stepped direct voltages from their common plate load to a single circuit. This is done without input to the amplifiers by adjusting the grid bias or by tapping the switched voltage E_s for different screen-grid voltages to each amplifier tube so that a different voltage is obtained across the common plate load for each amplifier tube. An example of this application is the determination of vacuum-tube characteristic curves. By the switching of some control voltage through a series of fixed values a set of curves of a tube under test can be viewed on a cathode-ray tube screen.

Frequency Division

By reference to figures 4 and 5, particularly figure 5, showing the transient voltages occurring across the series cathode resistors of the basic voltage-switching circuit, as shown in figure 12, the reader will see that for each complete switching cycle around such a symmetrical arrangement of switching tubes, the highest peak transient voltage occurs across the cathode resistor of the tube just being shut off (for any value of n) and that across any one cathode resistor this tran-



TYPICAL SWITCH OPERATING CONDITIONS

	CASE I	CASE II	
E_B	115	65	VOLTS
E_3*	100	50	VOLTS
E_K	-40	-36	VOLTS
E_C	-140	-100	VOLTS
C	0.002	0.0015	μf
R_2	5000	3000	OHMS
a	2.5	2.5	
b	1.4	2.0	
R_1	12,500	7500	OHMS
R_K	7000	6000	OHMS
$R_{K'}$	5000	3800	OHMS
R_g	200,000	120,000	OHMS
R_J	15,000	6500	OHMS
C_L	0.0001	0.00003	μf
$e_{L(MIN.)}$	60	80	VOLTS
E_{B1}	200	100	VOLTS
E_{P1}	164	88	VOLTS
E_{CC}	-2.5	-2	VOLTS

*$E_3 = E_B - 15$ VOLTS APPROX.

Figure 17. Complete diagram of a three-circuit amplifier-switch

sient of highest value will occur only once in a complete switching cycle. Since this highest transient peak voltage, of magnitude approximately equal to twice the switched voltage E, for $E_k \div 0$, appears at a frequency $1/n$ times the original impulse frequency F_i, it may be used to supply impulses to another electronic switch at a frequency F_i/n. This method may be carried on indefinitely; the output frequency of the last switch being $F_i/n_1\, n_2\, n_3 \ldots . n_n$. Since the values of n_1, n_2, n_3, ... may be different, practically any integral frequency division is possible. The output of the last switch may have the usual character of E, or be made impulsive according to the filtering used.

Operational Notes

Photographing

Although patterns obtained simultaneously may be photographed, it is necessary with high amplifier gains and desirable with low amplification, that the anode-voltage supply for the electronic switch and associated amplifiers should have good regulation. An exposure meter is helpful in predetermining the photographic requirements.

Wiring

All leads carrying high-frequency currents should be kept short, small, and well separated, particularly for high-frequency switching. Resistances and other circuit constants should, also, be chosen to meet the requirements of high-frequency operation.

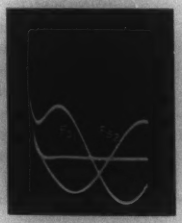


Figure 18. Oscillogram showing the application of the circuit of figure 17 to the observation of recurrent patterns

Permissible Variations in Circuit Constants

All constants nominally identical should in general be held as closely as feasible to the same values. The permissible departure from nominal values depends on the application.

Relation of the Triggering Frequency to the Signal Frequency and to the Pattern Frequency

All signal frequencies F_s must bear an integral ratio to the switching frequency F_i; otherwise, a nonexistent phase shift will be indicated between patterns of integral-frequency ratios. If a value of F_s is equal to $F_i/2$ or $F_i/4$, a half-wave or quarter-wave of F_s is shown, respectively. The pattern frequency, that is, the number of times a particular pattern is repeated per second, ordinarily is equal to F_i/n; hence, F_i bears the integral ratio n to F_p.

Formation of n-Tube Switching Circuits

No definite limit can be set for the number of switching tubes that can be used in an electronic switch without giving consideration to the application. Thus, at an impulse frequency F_i of 60 cycles per second, four circuits are about the limit for visual observation, since the pattern frequency F_p would be 15 cycles per second—not considered objectionable; if n equals five or six, F_p would be 12 and 10, respectively, for which flicker perhaps would be considered objectionable. For photographic purposes, however, the limit may be determined by the number of distinguishable wave forms. For example, 300 impulses per second (F_i), which would produce 15 patterns, each having a repetition frequency of 20 pictures per second (F_p) probably would be acceptable. For frequency division at low switching frequencies, a very large number of switching tubes probably could be operated successfully in each switch. At switching frequencies of 5,000 cycles per second or more, the number of circuits should not be greater than necessary in order that the time constants may be kept as low as possible. For these frequencies, every means should be used to keep the apparent transient time low.

Conclusions

The development of one type of basic switching circuit suitable for from two to a large number of controlled circuits has been discussed and some applications described. Emphasis, however, has been placed on the observation of multiple recurrent patterns on the screen of a cathode-ray tube.

This latter application allows the simultaneous viewing of phase displacement or relative wave forms of two or more currents or voltages, or both, as for example, the input and output voltages of an amplifier or filter. Circuits may be switched at frequencies from 0 to 50,000 cycles per second or more depending on the permissible interval for the switching. With a three-circuit switch for this application, the effective switching interval may be made less than ten per cent of a sweep cycle at a switching frequency of 10,000 cycles per second. The switching interval at lower switching frequencies will be progressively less.

The other applications described include (1) the switching of circuits with common ground, (2) the switching of one circuit to different voltages and (3) the obtaining of frequency division.

References

1. Electron Tubes in Industry (a book), **Keith Henney**. Page 171. McGraw-Hill Book Company, Inc., New York, N. Y.

2. A Cathode Ray Oscillograph for Observing 2 Waves, **R. H. George, H. J. Heim, H. F. Mayer and C. S. Roys.** Electrical Engineering (AIEE Transactions), volume 54, October 1935, pages 1095–1100.

3. Thyratrons for High Speed Counting, **Wynn-Williams.** *Proceedings* of the Royal Society, series *A*, volume 132, July 2, 1931.

News

Of Institute and Related Activities

Washington Provides Ideal Setting for the Institute's 1938 Summer Convention

WASHINGTON, D.C., is the city which perhaps every citizen of the United States plans to visit. It ranks with London and Paris as one of the great capitals of the world. The 1938 AIEE summer convention to be held there June 20–24 offers an extraordinary opportunity for combining business, pleasure, sightseeing, and education amid the national shrines, in a city that is neither northern nor southern, neither eastern nor western. Here are neighbors from every state. Within short distances are the Atlantic Ocean and Chesapeake Bay beaches, the mountain resorts of Virginia, and the Shenandoah Valley and its famous caves and historical spots relating to the founding of the Republic and the Civil War. Convention headquarters will be the Mayflower Hotel.

In the city are so many points of interest that the visitor will have to select rather than wonder what is to be seen. One may take a 500-foot vertical hike (or an elevator) up the Washington Monument, from which can be seen the skyline of the city from the one side and Virginia on the other. For the more serious minded, there are the Capitol and Congress, which may be in session at the time of the convention.

Washington is not an industrial city so that inspection trips to factories and power plants, features of many conventions, will be limited. However, there will be several from which members can select. Members desiring information before coming or who wish to see something especially, or contact a Government department may do so through the chairman of the publicity committee, H. E. Way, 155 East Quincy Street, Chevy Chase, Md.

Technical Sessions

A technical program, now in a formative stage and tentatively comprised of ten technical sessions and six conference sessions, promises to bring forth new developments in several different branches of the electrical industry. Technical sessions on the following subjects tentatively are scheduled, power transmission, communication, education, lightning protection, selected subjects, power system stability and electrical machinery, electronics, symposium on fluorescent lighting, fault interruption, and instruments and measurements. Subjects of the conference sessions are: basic sciences (two), modernization of power plants, power requirements in electrochemical and allied industries, electrical machinery, and electronics. The symposium on fluorescent lighting is of noteworthy interest. The development of this new light source with its pleasing color effects and attendant economies will be described thoroughly in several papers, and the session will conclude with a general lighting demonstration lecture by A. L. Powell (A'13, F'36) supervising engineer, incandescent lamp department, General Electric Company, New York, N. Y., and past-chairman of the AIEE committee on the production and application of light. Details of the technical program are scheduled for announcement in the June issue.

Inspection Trips in Washington

A program of inspection trips in Washington and in the near vicinity has been planned to include many points of interest. Arrangements have been made by which the following buildings and plants may be inspected on each day during the convention, except where noted otherwise. Guides will be available at all locations:

1. **Bureau of Standards.** This is an institution, operated by the Federal Government, devoted to the development of methods, standards of measurement, standard constants, and standards of quality performance, and practices.

2. **New High-Voltage Generator of the Department of Terrestial Magnetism of the Carnegie Institution of Washington** (Monday, Tuesday, and Friday only). This is an electrostatic machine capable of delivering constant potential at controlled voltages from 500,000 volts to 5,000,000 volts. The special steel pressure tank and building with underground laboratory rooms already are constructed to house this apparatus, and it is anticipated that the generating equipment will be ready for use before June.

3. **United States Navy Yard.** The guns for the Navy are constructed here, as well as the delicate and accurate apparatus for sighting and controlling their discharge.

4. **New Building of the Department of the Interior.** This represents the latest ideas and designs of mechanical equipment in the construction of a Government office building.

5. **United States Central Heating Plant.** This plant furnishes heat to practically all of the Government-owned buildings in the downtown area of Washington.

6. **Department of Justice—Federal Bureau of Investigation.** The investigation of Federal offenses, including kidnaping, and robbery of national banks and the United States mail, is centered here. Laboratories for chemical analysis, photography, and other scientific aids for detection of crime are maintained. Special arrangements for receiving the AIEE delegates at the Federal Bureau of Investigation will be made and definite hours set for this visit.

7. **United States Naval Observatory.** The function of this Federal-operated plant is to determine accurate time through daily astronomical observations and other astronomical data required by the Navy Department.

8. **Bureau of Engraving and Printing.** At this establishment, all stamps (postage, revenue, and tax), paper currency, and bonds issued by the United States Government are engraved and printed.

Principal Hotels in Washington, D. C., and Rates

Hotel	Single Room	Double Room
Downtown Area		
Mayflower, Connecticut Avenue & DeSales Street (convention headquarters)	$3.50–$6.00	$5.50–$10.00
Ambassador, 1412 K Street	$3.00	$5.00–$ 7.00
Burlington, 1120 Vermont Avenue	$2.50–$3.50	$3.50–$ 4.50
Colonial, 1156—15th Street	$2.50–$3.00	$3.50–$ 4.00
Hamilton, 14th & K Streets	$3.00–$4.00	$5.00–$ 7.00
Harrington, 11th & E Streets	$3.00–$3.50	$4.00–$ 7.00
Hay-Adams House, 800—16th Street	$3.00–$5.00	$4.50–$ 7.00
Carlton, 923—16th Street	$4.00–$6.00	$8.00–$ 9.00
Fairfax, 2100 Massachusetts Avenue	$3.00–Up	$4.00–Up
Lafayette, 16th & Eye Streets	$3.00–$3.50	$4.00–$ 6.00
Lee House, 15th & L Streets	$3.50–$4.00	$5.00–$ 8.00
Martinique, 1211—16th Street	$3.00–$3.50	$4.00–$ 6.00
Powhatan, 18th Street & Pennsylvania Avenue	$2.50–$3.50	$4.50–$ 6.00
Washington, 15th Street & Pennsylvania Avenue	$3.50–$4.50	$5.00–$ 7.00
Willard, 14th Street & Pennsylvania Avenue	$3.50–$4.50	$5.00–$ 7.00
Raleigh, 12th Street & Pennsylvania Avenue	$3.00	$5.00–$ 5.50
Residential Area		
Wardman Park, 2660 Woodley Road	$3.00	$5.00
Shoreham, 2500 Calvert Street	$4.00	$6.00
Capitol-Plaza Area		
Dodge, 20 E Street	$2.00–$5.00	$3.50–$ 8.00
Plaza, 331 First Street, N.E.	$2.50–$3.00	$3.50–$ 4.00
Commodore, North Capitol & F Streets	$2.50–Up	$3.50–Up
Bellevue, 15 E Street	$2.00–$2.50	$3.50–$ 4.00
Carroll Arms, First & C Streets, N.E.	$3.00–$3.50	$4.50–$ 7.00

Tentative Schedule of Events

Eastern Standard Time; See Separate Schedule for Sports

Monday, June 20

9:00 a.m.—Registration

10:00 a.m.—Opening Session
- Address of Welcome by Doctor William McClellan, honorary chairman
- Annual Business Meeting
- Annual report of board of directors, in abstract, by H. H. Henline, national secretary.
- Report of committee of tellers on (*a*) election of officers, and (*b*) constitutional amendments
- Introduction of and response from president-elect
- Presentation of Lamme Medal to Doctor R. E. Doherty
- Presentation of prizes for papers

2:00 p.m.—Inspection trips
- Conference of officers, delegates, and members

3:00 p.m.—Separate conferences
- (*a*) Section delegates
- (*b*) Student Branch counselors

7:00 p.m.—Student Branch dinner

8:30 p.m.—President's reception at Mayflower Hotel—dancing 9:00–12:00

Tuesday, June 21

9:30 a.m.—Power transmission
- Communication
- Education
- Conference on basic sciences

2:00 p.m.—Conference of officers, delegates, and members
- Inspection trips

7:30 p.m.—Dinner-dance at the Congressional Country Club

Wednesday, June 22

9:30 a.m.—General session

2:00 p.m.—Inspection trips
- Visit to Mount Vernon

4:00 to
6:00 p.m.—Tea at Doctor McClellan's, Burgundy Farm, Alexandria, Va.

Thursday, June 23

9:30 a.m.—Lightning protection
- Power-system stability and electrical machinery
- Selected subjects
- Electronics

12:30 p.m.—Board of directors' luncheon meeting—Mayflower Hotel

2:00 p.m.—Inspection trips
- Conference sessions:
  - (*a*) Modernization of power plants
  - (*b*) Electrical machinery
  - (*c*) Electronics
  - (*d*) Power requirements in electrochemical and allied industries

3:00 p.m.—Conference of vice-presidents, District secretaries, and counselor delegates

7:00 p.m.—Dinner—Mayflower Hotel
- Address: Doctor William McClellan, president of American Engineering Council.
- Presentation of Gaston Planté Medal to Doctor George W. Vinal by the French Ambassador
- Addresses by:
  - President W. H. Harrison
  - President-Elect John C. Parker
- Introduction of past-presidents
- Award of prizes for sports events

Friday, June 24

9:30 a.m.—Symposium on fluorescent lighting
- Fault interruption
- Instruments and measurements
- Conference on basic sciences

2:00 p.m.—Inspection trips

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9. Buzzard Point Power Plant. This is the base-load station of the Potomac Electric Power Company for the Washington system in connection with the Benning steam plant and the 230-kv transmission line from Safe Harbor (Pa.) on the Susquehanna River.

10. New Installation of Dial Telephone Equipment. The new Dupont central office of the Chesapeake and Potomac Telephone Company is the latest office of this type to be placed in service in Washington.

Out-of-Town Inspection Trips

Tuesday, June 21. Inspection of the cable and wire manufacturing plant of the Western Electric Company at Point Breeze, Baltimore, Md. At this plant is manufactured all of the rubber-insulated wire, submarine cable, and quadded cable used by the Bell System.

Thursday, June 23. Inspection of the 56-inch hot-strip mill of the Bethlehem Steel Company, Sparrows Point, near Baltimore, Md. This is the latest in hot-strip mills for the production of sheet metal.

Friday, June 24. Inspection of the Safe Harbor (Pa.) hydroelectric station of the Pennsylvania Water and Power Company. This will be an all-day trip.

Post-Convention Trips

In addition to trips during the convention, arrangements will be made, provided a sufficient number register for the purpose, to include several post-convention trips. These have been planned as follows:

1. Annapolis tour, leaving Mayflower Hotel at 2:00 p.m., Friday, returning at 6:00 p.m., covering the city of Annapolis and the United States Naval Academy, with a guide to explain the points of interest. $1.50 per person round trip; minimum number 15.

2. Gettysburg (Pa.) tour. Leave Mayflower Hotel 8:30 a.m., returning 6:30 p.m. Includes lunch at Gettysburg, tour with guide over the battlefield, and visit to the Barbara Fritchie House in Frederick, Md. $4.15 per person; minimum number 15.

3. Tour to Luray Caverns and Skyline Drive, leaving Saturday, 8:00 a.m. and returning at 6:00 p.m. Includes lunch and admission to the Caverns and 31 miles of Skyline Drive. $5.50 per person; minimum number 15.

4. Three-day trip through Virginia. This includes Old Point Comfort, Yorktown, Williamsburg, Jamestown, Richmond, Charlottesville, Wakefield, and Fredericksburg. This trip will be arranged starting Saturday morning at 8:00 a.m., returning about 6:00 p.m. Meals and rooms at hotels included. $24.25 per person; minimum number 15.

Sports and Entertainment

Sports and social activities of the convention will center at the beautiful congressional country club situated in Maryland, near the banks of the historic Potomac and almost in sight of the Capitol dome. Club facilities include spacious grounds and gardens, a large outdoor swimming pool, and a commodious club house.

Arrangements have been made for golf tournaments for the Mershon and Lee trophies, and also a tournament for the Mershon tennis trophy and a variety of men's and women's single and double tennis events. The detailed program proposed is as follows:

Monday, June 20

1:00 p.m.—18 holes of medal play on a handicap basis and qualifying round for the Mershon and Lee trophies.

2:00 p.m.—Table-tennis tournament—men and women.

2:00 p.m.—First round men's tennis singles.

3:00 p.m.—First round women's tennis singles.

Tuesday, June 21

1:00 p.m.—18 holes match-play finals for lowest net score of 36 holes, Lee-trophy events. First round of 16 players for match-play Mershon-trophy events.

2:00 p.m.—Table-tennis tournament—men and women.

2:00 p.m.—Second round men's tennis singles.

2:30 p.m.—Women's putting contest.

3:00 p.m.—Second round women's tennis singles.

4:00 p.m.—First round mixed tennis doubles. First round men's tennis doubles.

7:30 p.m.—Informal dinner-dance at the Congressional Country Club.

Wednesday, June 22

1:00 p.m.—18 holes second round match play for Mershon trophy.

2:00 p.m.—Semi-finals men's tennis singles.

3:00 p.m.—Finals of women's tennis singles. Semi-finals mixed tennis doubles.

4:00 p.m.—Semi-finals men's tennis doubles.

Thursday, June 23

9:00 a.m.—Semi-finals 18 holes match play for Mershon trophy.

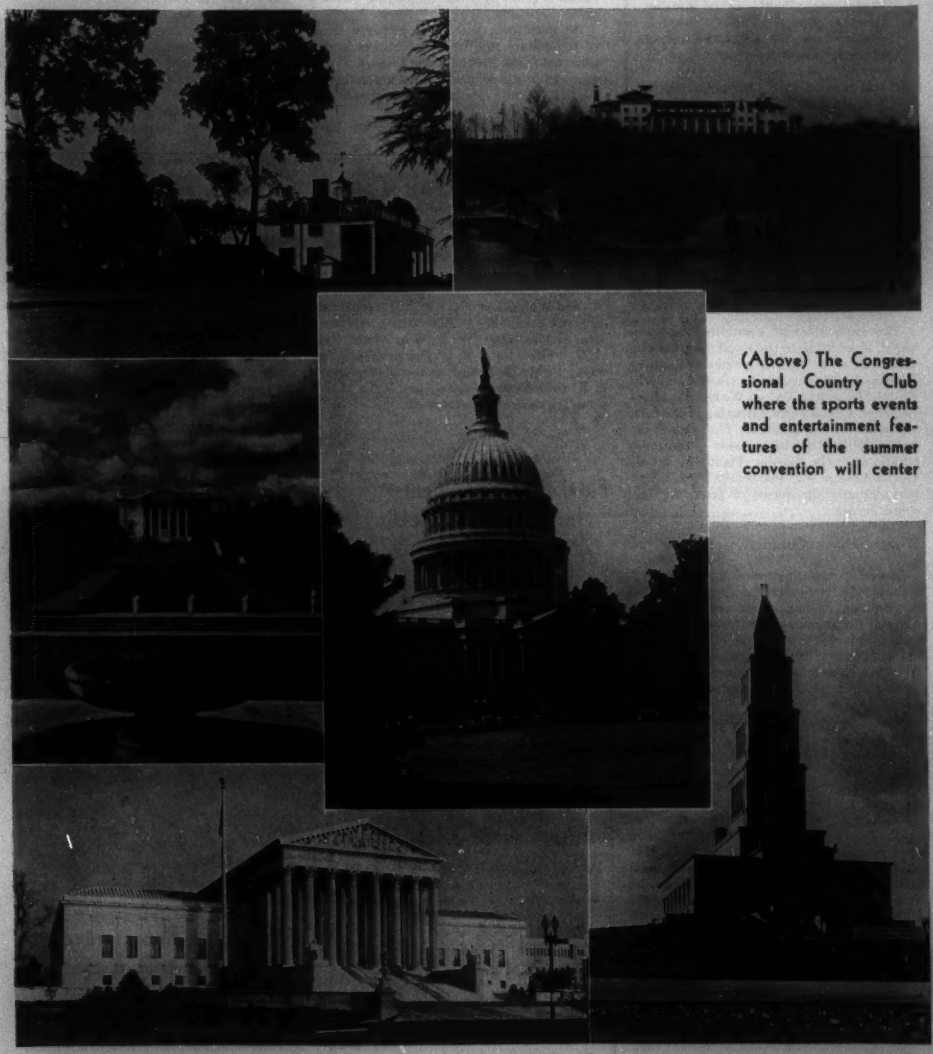
1:00 p.m.—18-hole final for Mershon trophy.

2:00 p.m.—Finals men's tennis singles. Finals mixed tennis singles. Finals mixed tennis doubles.

The golf greens fee is $2.00 per day. The charge for use of tennis court is 50¢ per day. Further details of the sports program will be included in a pamphlet available on registration at the convention.

Washington Beckons Summer Conventioners

Some of the attractions in and near the Nation's Capital, scene of the AIEE 1938 summer convention



(Above) The Congressional Country Club where the sports events and entertainment features of the summer convention will center

(Top) Home of the first president of the United States at Mount Vernon, Va. © H. H. Rideout

(Middle) Tomb of Unknown Soldier and Amphitheater, Arlington Cemetery © H. H. Rideout

(Bottom) Supreme Court Building © Harris and Ewing

(Center) The Capitol and some of its beautiful grounds Photo by R. E. Williams (A'35)

(Bottom) George Washington Masonic Memorial © H. H. Rideout

Notice of Annual Meeting

The annual meeting of the American Institute of Electrical Engineers will be held at the Mayflower Hotel, Washington, D. C., at 10 a.m. on Monday, June 20, 1938. This will constitute one session of the annual summer convention which is to be held this year in that city.

At this meeting, the annual report of the board of directors, and the reports of the committee of tellers on the ballots cast for the election of officers and for constitutional amendments will be presented.

Such other business, if any, as properly may come before the annual business meeting may be considered.

(Signed) H. H. HENLINE
National Secretary

The entertainment committee has provided, in addition to the usual program of a dinner-dance at the Congressional Country Club on Tuesday evening, a tea at Burgundy Farm, Alexandria, Va., on Wednesday afternoon and a final social gathering of the convention, a formal dinner on Thursday evening, which will be the occasion of the presentation of the Gaston Planté Medal to Doctor George W. Vinal by the French Ambassador and the award of prizes for the sports events.

Women's Entertainment

In addition to the entertainment features included in the schedule of events, the women's entertainment committee has arranged an attractive program, including visits to places of interest in Washington, a bridge-luncheon at the Congressional Country Club preceding the dinner-dance held at the club in the evening, and a tea at Burgundy Farm in nearby Virginia. The women of the local Section will provide transportation and personally conduct individual tours that the visiting women may wish to take.

Advance Registration

Members who will attend the convention are urged to register in advance by promptly returning the addressed advance-registration card, which they will receive by mail. This will be helpful to the committees and will permit badges to be made ready in advance, thus avoiding congestion at the registration desk.

A registration fee of $2.00 will be charged all nonmembers, except Enrolled Students and the immediate families of members.

Hotel Reservations

All members planning to attend the convention should make their own hotel reservations, and the committee urges that this be done well in advance. The Mayflower, the convention headquarters hotel, has guaranteed reservations for 150 single rooms, 100 double rooms with double bed, and 250 double rooms with twin beds; but in order to be sure of desired accommodations, members planning to make reservation at the Mayflower should likewise make such reservation well in advance. A list of the principal hotels in Washington and their rates (European plan) for single and double rooms is given in an accompanying tabulation.

All downtown hotels are within a five- to ten-minute ride from convention headquarters. The hotels in the Capitol Plaza area and in the residential area are within a 10- to 20-minute ride from convention headquarters.

The personnel of the 1938 summer convention committee is as follows: General committee—William McClellan, *honorary chairman;* H. W. Osgood, *chairman;* C. A. Robinson, *vice-chairman;* G. L. Weller, *secretary;* A. F. E. Horn, *treasurer;* F. A. Allner, R. C. Bailey, L. D. Bliss, J. V. B. Duer, N. E. Funk, W. B. Kouwenhoven, T. J. MacKavanagh, J. F. Meyer, J. S. Miller, H. S. Osborne, H. M. Southgate, and W. H. Timbie. Chairmen of subcommittees—Roland Whitehurst, *finance;* J. H. Stephens, *transportation;* W. J. Ellenberger, *registration and housing;* H. E. Way, *publicity;* A. O. White, *sports;* R. W. Prince, *inspection trips;* F. M. Defandorf, *technical programs;* S. K. Brown *entertainment;* and R. C. Marshall, Jr., *women's entertainment.*

Final Announcement for the Lenox Meeting

All is in readiness for the three-day meeting of the North Eastern District of the AIEE to be held at Lenox, Mass., May 18–20, 1938, with headquarters in the Curtis Hotel. A splendid program of entertainment, technical sessions, and inspection trips to nearby industries awaits those who will attend. Those planning to attend who have not already registered in advance, are urged to fill in and mail the advance registration card or write to L. G. Hamilton, chairman, hotel and registration committee, care of central station Department, General Electric Company, 100 Woodlawn Ave., Pittsfield, Mass.

A more complete announcement of the meeting, including information on the various features—entertainment, inspection trips, and the technical program—was published in the April issue, pages 176–7. Since then the following supplementary information in regard to the stag smoker and the speakers for the general session and the banquet has been made available.

Stag Smoker

The stag smoker at the Town Hall in Lenox on Wednesday evening, May 18, will be a very informal get-together and will include games, music, and entertainment probably by members of the General Electric Pittsfield works. It is requested that the men attending the meeting be prepared to take part in some good fun and, if convenient, bring along some old clothes. Should this be too inconvenient for some coming from out of town the entertainment committee may provide several old coats and other garments for those who are really interested. Another suggested alternative is to come without collars and neckties, in shirt sleeves, or in any manner which will emphasize the effect desired. There will be some competition between those with unusual costumes and all in all an evening of good fun and fellowship.

Speakers

For the general session on Thursday morning, May 19, two speakers have been engaged. Roger Babson will address the meeting probably on some economic subject; he is the founder and now president and chairman of the board of Babson's Statistical Organization, Wellesley Hills, Mass., and is a well-known lecturer on statistical and economic subjects. K. K. Darrow (A'19) research physicist of the Bell Telephone Laboratories, Inc., New York, N. Y., will give an address on natural and artificial radioactivity. Doctor Darrow is noted for his many writings and lectures on physical subjects; full text of his address appears elsewhere in this issue. The speaker for the mixed banquet on Thursday evening, May 19, will be W. H. Timbie (A'10, F'24) professor of electrical engineering at Massachusetts Institute of Technology, Cambridge. Professor Timbie is a past vice-president of the AIEE and is currently chairman of the Institute's Sections committee.

Future AIEE Meetings

North Eastern District Meeting
Lenox, Mass. (Pittsfield Section) May 18–20, 1938

Summer Convention
Washington, D. C., June 20–24, 1938

Pacific Coast Convention
Portland, Ore., August 9–12, 1938

Southern District Meeting
Miami, Fla., November 1938

Winter Convention
New York, N. Y., January 23–27, 1939

South West District Meeting
Houston, Texas, Spring, 1939

AIEE to Be Represented at Glasgow Congress

To represent the AIEE at the International Engineering Congress to be held at Glasgow, Scotland, June 21–24, 1938, A. P. M. Fleming (M'14, F'34) local honorary secretary of the AIEE, Manchester, England, and L. F. Morehouse (M'16, F'20) of London, have been appointed. The congress is being held in the conference hall of the Empire Exhibition, Scotland, 1938, which is scheduled to be open from May to October, and which includes a

palace of engineering covering an area of five and one-half acres.

A program of technical sessions, inspection trips to various industries, excursions, and social events has been arranged. Technical sessions will be held during the mornings of June 21 and 22 and will include a series of 15 addresses by outstanding British and other engineers dealing with various branches of engineering; the congress will sit in three simultaneous sessions for these addresses. Membership of the congress is open to members of any recognized technical society

Membership—

Mr. Institute Member:

Certainly, all of us appreciate the value of the work the Institute is doing to advance the profession of electrical engineering but only a few seem to realize that, as members, we also have an obligation to assist the Institute in improving its value to us. We can render this assistance through our help in securing new members; a larger membership naturally makes the Institute more representative of the profession, and incidentally permits increased and more forceful activities which benefit all of its members.

The Boy Scouts of America have a motto: "Do a good deed daily." It would be well if we adopted a similar motto, having a slight degree of retardation: "Get a new member yearly." Think what a force the Institute could be if we had 29,000 members instead of 14,500.

Be a good scout and give your membership committee just a little help.

E. T. Gunther

Vice-Chairman, District No. 7,
National Membership Committee

A membership proposal form appears on page 20 of the advertising section of this issue

AIEE Executive Committee Meets at Headquarters

A meeting of the executive committee of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., March 29, 1938, in place of the regular meeting of the board of directors.

Present: President W. H. Harrison (chairman), O. B. Blackwell, F. M. Farmer, C. R. Jones, A. M. MacCutcheon, W. I. Slichter, A. C. Stevens, members of the committee; C. R. Beardsley, director; H. H. Henline, national secretary.

Executive committee action on applications as of February 21, 1938, was reported as follows: two applicants transferred to the grade of Fellow; seven applicants transferred and 13 elected to the grade of Member; 43 applicants elected to the grade of Associate; 72 Students enrolled.

Reports were presented and approved of meetings of the board of examiners held February 17 and March 17, 1938. Upon recommendation of the board of examiners, the following actions were taken: eight applicants were transferred and 12 were elected to the grade of Member; 78 applicants were elected to the grade of Associate; 172 Students were enrolled.

The finance committee reported monthly disbursements amounting to $20,297.71 in February and $24,284.21 in March; report approved.

Recommendations of the finance committee, based on recommendations of the investment counsel of the Institute, concerning changes in the Institute's securities, were accepted and referred to the board of directors for letter ballot.

Approval was given to the holding of a joint session with the Institute of Radio Engineers during the AIEE Pacific Coast convention, in Portland, Ore., August 9–12, 1938.

Location and dates for the 1939 combined summer and Pacific Coast conventions were approved, as follows: Fairmont Hotel, San Francisco, Calif., June 26–30.

Report was made of the appointment of R. T. Henry as chairman of the standards committee's subcommittee on standardization of bushings.

The following recommendations of the standards committee were approved: (1) that the AIEE relinquish proprietary sponsorship of the committee on storage batteries—C40, with the understanding that it will be transferred to sectional committee procedure under American Standards Association and with AIEE sponsorship; (2) that the revised draft, prepared by the committee on protective devices, of the AIEE standard on oil circuit breakers be approved and printed as an Institute standard, it being understood that this standard then will be submitted to ASA for inclusion in a proposed American standard for oil circuit breakers under preparation by an ASA sectional committee on power switchgear.

Other subjects were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Pacific Coast Convention to Have Session With IRE

Following last year's successful innovation, a joint technical session with the Pacific Coast members of the Institute of Radio Engineers is being planned as one of the features of the AIEE 1938 Pacific Coast convention to be held in Portland, Ore., August 9–12, 1938. Approval of the joint session was given by the AIEE executive committee at its meeting of March 29.

As announced previously, the dates for the 1938 convention are almost a month earlier than in previous recent years so as to provide a better opportunity for those planning combined vacation-convention trips. Portland is in the heart of the Pacific Northwest with its many scenic attractions, and is within fairly easy reach of some of the national parks. Another attraction will be an inspection trip to the Bonneville navigation and hydroelectric project with its famous fish ladder. Details of the program will be announced in subsequent issues.

1938 AIEE Year Book Is Now Available

In accordance with the provisions of the Institute's 1937–38 budget as approved by the finance committee and the board of directors, the 1938 edition of the AIEE Year Book has been issued, in limited edition, and is available to members of the Institute who have use for it. The book contains essentially the same material as was included in the 1937 edition; business and mailing addresses have been corrected as of February 28, 1938.

In keeping with established custom, copies of the Year Book have been distributed to all national, District, and Section officers, to Student Branch counselors, and to all members of all national committees. Other members wishing to secure a copy may do so by writing to the AIEE order department, 33 West 39th Street, New York, N. Y., giving correct mailing addresses.

The Year Book is not available to nonmembers of the Institute, nor is its use permitted for commercial, promotional, or other circularization purposes.

New York Section Group Inspects the "Lord Kelvin"

On March 28, 1938, 312 members of the communication group of the AIEE New York Section inspected the Western Union cable-repair ship "Lord Kelvin" while it was in port to load a 4,200-foot chain to be used for towing a submarine-cable plow (see article elsewhere in this issue). The accompanying illustration shows a group of visitors inspecting the equipment on the foredeck.

Fluorescent Tubular Lamps Soon to Be Available

At a joint meeting of the New York Electrical Society and the New York Sections of the Illuminating Engineering Society and the AIEE, held in New York, N. Y., April 21, 1938, new fluorescent light sources were described and their early commercial availability was announced. Speakers at the meeting were Ward Harrison (F'36) director of engineering, General Electric Company, Nela Park, Cleveland, Ohio, and S. G. Hibben (A'34) director of applied lighting, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J. The laboratory development of these lamps was announced about two years ago (*EE May '36, p. 560*).

The new lamps, which are designated "fluorescent lumiline lamps," provide light of almost any color or tint at efficiencies much higher than those at which colored light may be obtained from incandescent lamps. In physical appearance and dimensions, the lamps are similar to the present incandescent "lumiline" lamps, but are entirely different in their operation. Specially compounded and heat-treated powders are applied to the insides of the tubes. These powders fluoresce when activated by ultraviolet radiation, reradiating the ultraviolet energy in the form of visible radiation. The ultraviolet radiation in the lamp is produced by a trace of mercury and a small amount of argon gas at low pressure.

Each fluorescent powder has its own characteristic wave band with which it responds to ultraviolet radiation, thus forming its own particular color of emitted light. By the proper selection and blending of powders it is possible to produce light of practically any color or tint. The efficiencies of the lamps are much greater than those of colored incandescent lamps, but vary within fairly wide limits. For example, the green lamp has been found to be most efficient, producing 60 lumens per watt in the 30-watt size; blue is least efficient, producing about 20 lumens per watt; white light is produced at about 30 lumens per watt. The 20 lumens per watt of the blue lamp compares with 0.3 lumen per watt of the blue incandescent lamp. The light from the "daylight" fluorescent lamp is said to be the nearest approach to natural daylight that has ever been produced by an artificial illuminant, the color temperature closely approximating 6,500 degrees Kelvin.

Like all gaseous-conductor lamps, the fluorescent lamps require special transformers; they attain full brilliancy in a few seconds. A wide field of application for these lamps is predicted. At present they will be available in 15-, 20-, and 30-watt sizes the length of these being, respectively, 18, 24, and 36 inches, with tube diameters of one inch for the 15- and 20-watt sizes and one and one half inch for the 30-watt size.

Hydroelectric Power in Washington. Part V (Bulletin No. 95) of a series of bulletins on hydroelectric power in the state of Washington recently has been published by the engineering experiment station of the University of Washington. This part, a bibliography of technical papers relating to hydroelectric developments in Washington, supplements a previous bibliographic bulletin published in 1926, listing all generally available technical papers published during the ten-year period 1926–36. The complete list of bulletins in this survey, all compiled by C. E. Magnusson (A'05, F'13) professor of electrical engineering and director of the engineering experiment station at the university, is as follows:

Part I (Bulletin No. 26)—A Reconnaissance Survey, 1924.

Part II (Bulletin No. 36)—A Bibliography of Technical Papers, 1926.

Part III (Bulletin No. 78)—A Brief on Proposed Grand Coulee Dams, 1935.

Part IV (Bulletin No. 90)—Regional Electric-Power Transmission. The Grid System, 1936.

Part V (Bulletin No. 95)—A Bibliography of Technical Papers, (1926–36), 1937.

Part VI (Bulletin No. 96)—International Boundary Waters, 1937.

Requests for bulletins and reports should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle.

New Heating and Ventilating Guide. The Heating, Ventilating, Air Conditioning Guide 1938, 16th edition of the official reference book compiled by the American Society of Heating and Ventilating Engineers, was published recently. The 1938 edition contains 840 pages of technical reference data included in 45 chapters covering material on design and specifications of heating, ventilating, and air-conditioning systems. It contains new material on the cooling phases of air-conditioning practice, with revised chapters on refrigerants and air-drying agents, cooling-load determinations, and design of central systems for cooling and dehumidifying. A chapter on air conditioning in the treatment of disease appears for the first time. A new feature of the book is a visual chapter index. In addition to the technical material, over 300 pages of manufacturers catalog data are included, as well as an index to modern equipment listing 300 items, cross-indexed as to product and manufacturer. A complete listing of society members, including their professional or business affiliations, forms a separate section. Approximately 100 different experts assisted the guide publication committee of the society in compiling the 1938 volume. Single copies of the guide are available at $5 from the society headquarters, 51 Madison Ave., New York, N. Y.

Testing and Application of Lightning Arresters

For some time information dealing with the testing and application of lightning arresters has been needed. To provide such information, two memoranda entitled "General Guide for Utilities on Methods of Testing Lightning Arresters" and "Factors Affecting Application of Arresters" have been prepared by the lightning arrester subcommittee of the AIEE committee on protective devices.

The memorandum on the testing of lightning arresters describes three suitable circuits for making 60-cycle tests, suggests a simple test procedure, and provides information that will assist in the interpretation of test results. The memorandum on the application of arresters discusses the factors that should be given consideration in the selection of ratings of surge protective devices. The various types of lightning arrester connections used for distribution-transformer installations also are described, and a simplified method of identification for the various types of interconnections is suggested.

Advance copies of "Testing and Application of Lightning Arresters," AIEE Technical Paper No. 38–43, which contains both memoranda, have been made available because the paper will be scheduled on the program of the 1938 Pacific Coast convention. Copies may be obtained by mail by addressing the AIEE order department and enclosing remittance of 10¢ per copy; if purchased at headquarters, the price is 5¢ per copy.

New York Power Group Awards Paper Prizes

For several years, one of the annual meetings held by the power group of the AIEE New York Section has been a "volunteer paper program" consisting entirely of papers selected from voluntary submissions. This

year, for the first time, two cash prizes were awarded. The meeting, which was held April 14, 1938 in the Engineering Societies Building, was attended by about 150 members and guests.

From the nine papers submitted for consideration, the following four were presented:

BRUSH ECONOMICS, **K. B. Hoffman** (A'34) Consolidated Edison Company of New York, Inc.

AN ENCLOSED IMPROVED NETWORK-PROTECTOR FUSE, **Woodman Perine** (A'35) Consolidated Edison Company of New York, Inc.

SELECTING PROPER SIZE OF ELECTRICAL WIRE AND CABLE, **Ludwig F. Roehmann** (M'37) Anaconda Wire and Cable Company.

SHUNT CAPACITORS FOR DISTRIBUTION CIRCUITS, **Peter White** (A'37) Phoenix Engineering Corporation.

All four authors were coached by the instructor of the public-speaking courses conducted by the Section; 15 minutes was allowed for the presentation of each paper.

First prize of $50 was awarded to Mr. Perine; second prize of $25 to Mr. Hoffman. Judges of the contest were R. E. Powers (A'33) engineering manager, eastern district, Westinghouse Electric and Manufacturing Company; W. I. Slichter (A'00 F'12, national treasurer), professor of electrical engineering, Columbia University; and Philip Sporn (A'20, F'30) vice-president and chief engineer, American Gas and Electric Service Corporation.

Student Conference Held at VMI

A total of 172 students in electrical engineering and Student Branch counselors registered at the annual student conference of the AIEE Southern District, held at the Virginia Military Institute, March 24–26. Representatives were present from every one of the 18 Branches in the District:

Alabama Polytechnic Institute, Auburn, Ala.
University of Alabama, University, Ala.
Clemson Agricultural College, Clemson, S. C.
Duke University, Durham, N. C.
University of Florida, Gainesville, Fla.
Georgia School of Technology, Atlanta, Ga.
University of Kentucky, Lexington, Ky.
Louisiana State University, Baton Rouge, La.
University of Louisville, Louisville, Ky.
Mississippi State College, State College, Miss.
North Carolina State College, Raleigh, N. C.
University of North Carolina, Chapel Hill, N. C.
University of South Carolina, Columbia, S. C.
University of Tennessee, Knoxville, Tenn.
Tulane University, New Orleans, La.
Virginia Military Institute, Lexington, Va.
Virginia Polytechnic Institute, Blacksburg, Va.
University of Virginia, University, Va.

The only scheduled activity on Thursday, March 24, was an informal smoker given by the VMI Student Branch. A number of visitors arrived in time to visit neighboring points of historic interest and scenic beauty.

Six student papers were presented at the technical session on Friday morning, March 25:

USE OF NEON LAMPS TO INDICATE CORONA LOSS, **Edward G. Outlaw**, University of North Carolina.

VOLTAGE REGULATION OF ALTERNATING-CURRENT TRANSFORMERS, **Harry B. Brown**, Alabama Polytechnic Institute.

AN OPTICAL TACHOMETER, **J. Robert Rombach, Jr.**, Tulane University.

ELECTRICALLY GENERATED SUPERSONIC WAVES, **Raymond G. Tessmer**, Virginia Polytechnic Institute.

CONSTRUCTION OF AN INDUCTION FURNACE, **W. M. Furlow, Jr.**, Georgia School of Technology.

THE APPLICATION OF SYMMETRICAL COMPONENTS TO PROTECTIVE RELAYING, **Louis A. King**, University of Tennessee.

The first prize was awarded to L. A. King and the second to J. R. Rombach. E. G. Outlaw and R. G. Tessmer tied for third place. The prizes were $15, $10, and two of $5.

A business session was held Friday afternoon. It was decided that the next student conference of the Southern District would be held in Miami, Fla. in conjunction with the AIEE Southern District meeting. Professor E. F. Smith of the University of Florida was unanimously elected chairman of the District committee on student activities and was designated to represent the committee at the next summer convention.

A military review was held in honor of the visitors. The infantry companies, the cavalry troop, and the field artillery battery made an inspiring picture.

The attendance at the annual dinner was 191. The principal speaker of the evening was Doctor Dugald C. Jackson, past-president of the AIEE. Others on the program were Edwin D. Wood, AIEE vice-president, and H. H. Henline, national secretary.

A dance, called the AIEE Ball, was given by the corps of cadets Friday evening, and all conference visitors were invited.

Publication on Photoelasticity. "Photoelastic Journal" edited by A. G. Solakian at 55 West 42d Street, New York, N. Y., recently made its appearance with volume 1, number 1, issued under date of January 1938. Stating that it will concern itself with stress, polarized light, and plastics, this periodical sets itself the following objectives: "(1) To make photoelastic method of stress analysis simple in principle, practical in application, and popular in use; (2) to develop photoelastic research with a view of applying it to the economic and safe design of machine and structural elements; (3) to develop a close contact and co-operation between photoelasticians and industrial organizations; (4) to keep the reader informed with up-to-date developments of photoelasticity and relative subjects here and abroad; (5) to make photoelasticity accessible to a larger group of students, teachers, researchers, practicing engineers, educational and industrial organizations, etc."

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YOVTHS PRESSING VP THE HILL OF SCIENCE WITH NOBLE EMVLATION
A GRATIFYING SPECTACLE AN HONOR TO OVR COVNTRY AND OVR
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SPECIMENS OF CITIZEN SOLDIERS ATTACHED TO THEIR NATIVE STATE
PROVD OF HER FAME AND READY IN EVERY TIME OF DEEPEST PERIL
TO VINDICATE HER HONOR OR DEFEND HER RIGHTS

A group of those that attended the Southern District Student Branch conference at Virginia Military Institute

Annual Economics Conference. Sponsored jointly by Stevens Institute of Technology and the Society for the Advancement of Management, the Eighth Annual Economics Conference for Engineers is scheduled to be held at the Stevens Engineering Camp, Johnsonburg, N. J., from June 24 to July 2. The conference group will be divided into six sections on motion and time study, human relations, marketing, industrial management, and management problems. Four daily sessions are scheduled for each of the six sections, and one section will serve as a round table for teachers of management. Afternoons will be devoted to informal conferences and recreation, and each evening a prominent speaker will address the conference. Information may be secured from Professor G. W. Barnwell, director of the 1938 conference, Stevens Institute of Technology, Hoboken, N. J.

Future Meetings of Other Societies

American Association for the Advancement of Science. Summer meeting, June 27–July 2, Ottawa, Can.

American Iron and Steel Institute. General meeting, May 26, New York, N. Y.

American Physical Society. 221st meeting, June 22–24, 1938, Pacific Coast section in affiliation with AAAS, San Diego, Calif.

222d meeting, June 24–25, Toronto, Ont., Can.

American Society for Testing Materials. Annual meeting, June 27–July 1, Atlantic City, N. J.

American Society of Civil Engineers. Annual convention, July 20–22, Salt Lake City, Utah.

American Society of Mechanical Engineers, Semiannual meeting, June 20–24, St. Louis, Mo.

Canadian Electrical Association. Annual convention, June 22–24, Seigniory Club, Province of Quebec, Can.

Edison Electric Institute. Annual convention, June 6–9, Atlantic City, N. J.

Illuminating Engineering Society. Annual convention, Aug. 29–Sept. 1, Minneapolis, Minn.

Institute of Radio Engineers. Annual convention, June 16–18, New York, N. Y.

International Conference of Naval Architects and Marine Engineers. June 16–18, London, England.

International Engineering Congress. June 21–24, Glasgow, Scotland.

National Electrical Manufacturers Association. Spring conference, May 15–20, Hot Springs, Va.

Pacific Coast Electrical Association. Annual convention, May 26–27, San Francisco, Calif.

Society of Automotive Engineers. Annual meeting, June 12–17, White Sulphur Springs, W. Va.

Society of Chemical Industry. Annual meeting, June 20–22, Ottawa, Can.

Society of Naval Architects and Marine Engineers. Spring meeting, May 17, Washington, D. C.

Current Items From American Engineering Council

No Patent Legislation This Session of Congress

Congressman McFarlane and his associates have substituted H.R. 10068 for H.R. 9259 and thus changed many of the implications of current patent legislation. Moreover, Council's staff reliably is informed that no compulsory licensing of patents or similar threat to change patent regulations radically is in the schedule of bills to come up for action during this session of Congress. In fact, proponents of such legislation are no longer in a mood to fight for it.

Congressman McFarlane's new bill, H.R. 10068, simply proposes to amend section 35 of the revised statutes to provide for compulsory license where there is satisfactory evidence that a patent is not being used after the expiration of five years from date of issuance. In other words, the inventor would have an absolutely exclusive right to his patent for five years, but would have to put it into use within a period of five years to maintain all of the rights originally granted under his patent to the exclusive use of his invention or discovery.

As a basis for the equitable determination of royalties where licenses might be ordered under this revision of the statute, provision is made for filing an itemized statement with applications for patents setting forth the time and expense devoted to the development of the patent together with an appraisal of the intrinsic value of the invention or discovery, in so far as such an estimate is possible at that time.

Program for 1938 Includes Five Groups of Activities

As an outgrowth of the discussions and recommendations of the 1938 annual meeting of the AEC assembly held during January, the AEC executive committee has approved the following program for 1938.

With determination to use all resources at its command, most effectively, the management of the American Engineering Council has surveyed the field of its opportunities for 1938 and selected five groups of activities as being most likely to serve useful purposes among members of member organizations and the general public in the immediate future. They constitute a program which may tax Council's facilities, but they conform to the wishes of our assembly and executive committee; and a part of the program is already being translated into action.

I. Public-Affairs' Function

Serving through its staff and committees, as an interprofessional instrumentality for the presentation of the engineers' viewpoint on all phases of public affairs where engineering knowledge and experience are involved and the considered opinion of the engineering profession may be of public service, the American Engineering Council will:

1. Upon request, transmit engineering opinion and factual information to the Federal Government, including both legislative and administrative branches.

2. Make unbiased interpretations for the engineering profession of Federal laws, rules, regulations, and practices and report them through its publications and releases.

II. Public-Discussion Function

In co-operation with member societies, the American Engineering Council is initiating the practice of holding forums in which public problems related to engineering will be discussed by engineers for the purpose of clarifying and co-ordinating engineers' opinions. Initial forums are being arranged in eastern cities. Experience with the earlier forums will determine the expansion of the public discussion function toward a broader consideration of public problems.

III. Engineers'-Embassy Function

The staff of the American Engineering Council will continue to render as much service as possible under existing circumstances to member societies and their individual members on matters related to engineering arising from or connected with the Federal Government and its several branches.

IV. Publicity Function

The results of the functions outlined above are to be reported regularly to member organizations. In fact, within the limitations of funds, personnel and facilities, the American Engineering Council is increasing the volume of its publications and endeavoring to improve their effectiveness. The schedule for 1938 includes:

1. A change in title, appearance and editorial policy in Council's monthly publication.

2. A greater number of releases to member societies including their editors and boards of direction, and to the "press" regarding Council's activities and observations.

3. Use of annotated bibliography of articles expressing engineering opinion on matters of broad interest to engineers as an aid in integrating the work of AEC with all phases of related professional engineering opinion.

V. Fact-Finding Function

The functions referred to above have been selected from the many useful services which the American Engineering Council might perform. Several others should have consideration. Of such possibilities, the following have been selected for attention, if time permits, and if additional financing can be secured for such activities:

1. A fact-finding investigation of the situation surrounding employment of engineers and the

relation to their employment of unionization and registration. In the meantime, Council will continue actively to support the merit system in public service under civil service, and in its conferences with government officials Council will endeavor to have them avoid unnecessary government competition with engineers in private practice.

2. A survey to determine the effect on employment of technology. As opportunities present themselves, Council will continue to crystallize public opinion of research, invention, and scientific investigation into appreciation of the true value of the broad field of technology as an entirely practical means for opening up new frontiers of employment and new sources of wealth essential to the attainment of that higher standard of living, which has become generally accepted as the next major advance in our civilization.

3. A study of the relation of engineering to economics in public questions involving the capital goods, construction, extractive, and process industries in which engineers play the double role of being technically associated as employees and functionally related as managers of enterprises. The controlling factor is likely to be financing, but it is believed that influential members of member societies may be able to aid Council in interesting some of the foundations.

In carrying out this program, in 1938, the American Engineering Council will continue to be guided by consideration of the public interest and the enlargement of public understanding of the professional responsibility of the engineer in the United States. Neither officers, staff nor the committees will lose any opportunity to serve the engineering profession and more particularly members of member societies as a clearing house for factual information regarding the engineers' economic status in private practice or as an employee of public and private enterprise.

WILLIAM MCCLELLAN
President

FREDERICK M. FEIKER
Executive Secretary

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Cable and Damper Vibration Studies

To the Editor:

In the article "Cable and Damper Vibration Studies," published in ELECTRICAL ENGINEERING, June 1936, pages 600–14, L. A. Pipes develops a mathematical method of calculating the damping action of vibration-free cables (see also International High-Tension Conference 1935 Report No. 128). The results of this calculation do not agree with actual practice. From this fact it may be assumed that the assumptions which L. A. Pipes found it necessary to use in order to make the difficult problem mathematically possible are wrong.

The fact is that the vibration-free cables proposed by me actually do not vibrate. These cables of a total length of 44,000 meters (1936) have been tested by special experimental devices in practical use for more than two years and only an occasional slight clicking can be heard.

A short time ago a cable of 600 meters length, which had been operating for 14 months on a test span, was taken down for examination. A control cable of ordinary construction was erected parallel to the special cable. The standard cable vibrated about two-thirds of the time; the special cable was completely motionless.

The special cable was then cut to pieces and thoroughly examined for signs of abrasion. Effective magnification revealed no such signs on the individual wires. The zinc galvanizing of the cable core was entirely intact. This was proved by means of the well-known test of dipping the cable into a solution of copper sulphate. Because of the very small play, deformations and abrasions are impossible. Experience should be more convincing than opinions, even if commonly held.

In damping systems it is not the question of suppressing and counteracting existing vibrations, but rather that of preventing vibrations at their source. Let us therefore study the causes.

It is generally known that eddy currents of the wind are responsible for the initiation of vibrations. These eddy currents, when the wind is blowing, break loose behind the cable more or less perpendicularly to the direction of the conductor and give to the cable impulses which are vertical for horizontal winds. These act on the cable alternately in the upward and downward directions. The frequencies of these impulses have some relation to the velocity of the wind. If the frequencies of these impulses correspond with the natural frequency or are higher harmonics of the natural frequency of the cable, a vibration may arise in it. In addition to this it is necessary that the release of the air eddies scattered arbitrarily over the length of the cable be brought into a certain order, namely, they must be forced by some means to give their impulses to the cable at the right moment and at the right spot in order to initiate vibration. In the same way in a steam engine it is not sufficient to have the steam enter under pressure into the cylinder in order to get the reciprocal motion of the piston. The release of the eddy currents has to be controlled if they are to initiate the vibration of the cable. This control is performed by the movements of the cable. If accidentally on account of adjustments of supports due to temperature changes, or if incidentally on a certain length of the cable the initiation of eddy currents take place simultaneously and in a suitable sense or direction so that the impulse is strong enough to move the cable just a little bit, then there arises a traveling wave which runs in two or more directions at the velocity of propagation of waves. The movement of the cable prematurely frees the eddies which are poised or otherwise ready, and these eddies in their turn give their impulses to the cable. In this way the traveling wave grows larger. From the point of origin, other traveling waves, with the frequencies of the first eddies, will follow and loosen more and more eddies prematurely and co-ordinate them into the system. By the movement of the cable the freeing of eddy currents is controlled in such a way that they always give their impulses to the cable at the right moment. In this manner only is the arising of a vibration possible.

This theory explains an observation, namely, that all the cables of a line do not start vibrating at the same time. In case the cables are motionless, then a sufficient number of eddies to arouse a traveling wave sufficiently strong to control the other eddies has not been initiated. If such a cable is given a little shock, as mentioned above, a real vibration arises.

This explanation seems necessary in order to prove that a damping of vibrations can only be successful if the initiating of movements of the cable can be suppressed. In the proposed vibration-free cable, small traveling waves are suppressed in a short time. The damping effect of the cable construction is more powerful than that energy released from the air eddies. Therefore, in this cable, the amplitude of a traveling wave does not increase; rather it diminishes, and the wave very soon disappears completely.

In the vibration-free cable, the hollow cable and the core cable have such tensions that they try to take different catenary curves. (These facts were pointed out in a report, No. 128, of the International High-Tension Conference, Paris, 1935.) The hollow cable lies upon the core cable with only a part of its weight. Due to the traveling wave, the hollow cable lifts itself off the core cable when the force resulting from the mass of the hollow cable and the acceleration of the motion is stronger for the small sections of the cable than the pressure of the hollow cable, due to its weight, upon the core. The lifting off and falling back of the two cables results in damping, which may be explained by the absorption of energy and by disturbances in the velocity of propagation of waves.

These considerations explain why, in the construction and in the mathematical analysis of vibration-free cables and damping systems, the starting point cannot be the fact that the cables are already vibrating and that these vibrations have to be damped. It must rather be the fact that there must not arise any vibrations at all. The best construction is that which suppresses the initial movement of the cable. Having eliminated the larger vibrations, the movement of the two parts of the vibration-free cable against one another is

very weak and occurs very seldom. This is the reason why there is absolutely no destructive effect observed.

Besides these merely theoretical arguments, the satisfactory results of the tests with vibration-free cable on lines in use prove our expectations were right. Today the vibration-free cable is no longer a merely theoretical proposition, as Mr. Pipes writes in his article, but a thoroughly tested construction in the use of which difficulties are not now expected. In Germany, a new 100-kv line 56 kilometers long is now to be equipped with vibration-free cable. The installation is based on the entirely satisfactory results of the observations made on several existing lines of various lengths equipped with steel-aldrey and steel-aluminum cables.

The cables and installations are not much more expensive than for more standard conductors in use. There seems no reason why general use of vibration-free conductors cannot be expected.

Very truly yours,

MAX PREISWERK

(Chief Engineer, Société Anonyme pour l'Industrie de l'Aluminium, Neuhausen, Switzerland)

Registration of Engineers

To the Editor:

Actuated by the request for information on registration as made by Louis S. Leavitt (A'24, M'28) and published on page 42 or the January 1938 issue ELECTRICAL ENGINEERING, and noting the apparent need for enlightenment in this particular case, I offer the following facts for consideration.

I have had dealings with two state boards as well as the National Council of State Boards and have nothing but the highest praise for the efficient and entirely impersonal and ethical manner evidenced by these bodies.

Regarding Mr. Leavitt's guesses, predictions and humble opinions to the effect that registration will affect the profession adversely by degenerating into a political racket and lowering our ethics, I have seen no indications in any of my dealings with the various boards mentioned to substantiate such a viewpoint.

Regarding Mr. Leavitt's implications that it might be well to start a "backfire aimed at removing the law from the books," it seems to me that such words are rather hasty and uncalled for, especially in view of the prima-facie evidence of lack of information contained in his request for factual data.

It is, of course, regrettable that the profession should find dissension in its own ranks on this matter. Complete accord should be our aim if we are ever to achieve a status among the learned professions commensurate with our worth.

We lag considerably in respect to our professional status as evidenced by the lack of recognition accorded by the laity. This statement is borne out in one respect by the increasing indiscriminate use of the word "engineer."

As Mr. Leavitt points out, no factual data has been published in ELECTRICAL ENGINEERING regarding registration laws now in effect. I believe it would be well to inform the membership on these matters. It apparently seems to be vitally necessary.

Regarding our economic status, which has been so ably presented recently in ELECTRICAL ENGINEERING, I have always felt that it is more or less dependent on the establishment of our professional status. In other words, until the latter is definitely established, the former is bound to lag in direct proportion therewith.

On this premise, I have always welcomed any attempt to raise the professional standing of the engineering profession, and in consequence have of my own volition sought and obtained registration whether needed or not.

I have found over a period of 15 years, that registration has in no wise injured my professional standing in any respect, and that, on the contrary it has on several occasions been of inestimable assistance thereto.

Even though I do not happen to come under the requisite classification given by Mr. Leavitt of having "been *forced* to go over the hurdles in securing registration" and cannot classify this letter as a "brotherly act" I believe it contains the type of information which has been requested.

Sincerely yours,

C. SWAIN LUMLEY (A'23, M'29)

(Assistant Electrical Engineer, City of Detroit, Mich.)

Preparation of Manuscripts

To the Editor:

I read with pleasure your bulletin on "Preparation of Manuscripts" and I again take a jab at your policy of publishing as first and foremost school and college papers. I refer to the mathematical formula that invariably occupies first place in the journal. This is, no doubt, of interest to professors and some students but it is not a subject of interest to a substantial group of members. A lot of members may glow with pride that they should be considered interested in such mathematical fairy tales but such matter does not promote the engineering business of the country. As a country's prosperity depends entirely on business, and business depends on engineering, your magazine should devote itself to business material because the schools and colleges are already endowed.

I read further in your instruction that mathematical formulae should be given in an appendix when invariably it is the main part of the journal. Engineering is absent without business to support it. Some people claim that mathematical studies disclose new paths to follow. I think Michael Pupin's contributions are given as an example. I happen to know that Pupin filled several rooms with wires and spent hours of hard work to arrive at his solution. I was fortunate enough to pass integral calculus 100 per cent at Columbia under J. Howard Van Amringe. That is, he gave me a mark of 10. Probably I did not deserve it but it showed I was as good as the average in that day. Ever since then I have not had or could see any use for it in the engineering business world. The catenary was figured out long before I was born. It was just a mental exercise for me to do it. To continue training for a prize fight without ever holding the match seems silly to me.

It frankly gets my goat to see this psychic attitude in the AIEE journal. How about publishing this letter, or part of it, and see if you get any comments.

I also want to state right here that I read your explanations of electronics and how the atom is held together with a "nutron" [sic]. I want to go on record that I do not believe it.

Very truly yours,

C. J. HOLSLAG (M'19)

(President, Electric Arc Cutting and Welding Company, Newark, N. J.)

Electron Theory

To the Editor:

I was very much attracted by a paper appearing in the January issue of ELECTRICAL ENGINEERING entitled "Electron Theory." This paper is so outstandingly well written that I feel as though I should express my appreciation of it to you and its author, Professor R. G. Kloeffler of Kansas State College, Manhattan. It seems to me that the manner of presenting this article is much to be commended and should be taken as a model in writing many other technical papers.

Personally I have been much occupied in recent years with making a living and I had never taken up the study of electron tubes which seem destined to play an increasingly important part in our lives. Recently I have frequently felt the need of such knowledge and have consulted certain authorities. I was almost immediately plunged over my head in higher mathematics which I had not the desire nor the freshness of study to go into. The thing that makes Professor Kloeffler's article so very interesting and informative is that he has succeeded in explaining completely, a complicated and broad subject in such a way as entirely to omit mathematics but still make the subject plain to any one who will read it with concentration.

I think it is true that a very large number of men in our profession do not keep their mathematics in working order. Of course, a few do and there are some subjects that cannot be treated except at undue length without resort to mathematics and I have no quarrel with this form of presentation beyond the fact that I do not think it reaches any large number of readers.

I have long been an advocate of teaching and helping the technical man to a better form of expression than he now has and I think the article in question very fully carries into effect the ideal to which my thoughts have worked. It often seems a pity that men in possession of invaluable information to their own profession and to the public, as a general thing, are unable to impart it in such a way that it could be assimilated by other technicians and particularly by intelligent laymen.

Yours very truly,

ALBERT MILMOW (M'30)

(Sales Engineer, Charlotte, N. C.)

Personal Items

W. H. HARRISON (A'20, F'31) has been elected vice-president and chief engineer of the American Telephone and Telegraph Company, New York, N. Y. Mr. Harrison, president of the Institute, formerly was assistant vice-president of the department of engineering and operation of the company. He was born June 11, 1892, at Brooklyn, N. Y., and was graduated in industrial electrical engineering at Pratt Institute in 1915. He entered the employ of the New York Telephone Company in 1909, where his work until 1915 included apparatus inspection, assembling, and wiring. From 1915 to 1919 he was engaged in telephone circuit design in the engineering department of the Western Electric Company, and in 1919 he became a member of the engineering staff of the American Telephone and Telegraph Company. In 1924 Mr. Harrison was made equipment and building engineer with general supervision of the engineering of the subscribers station and central office plant of the Bell telephone system, and in 1929 he became plant engineer, with broad responsibilities including general direction of the engineering, design, and layout of all departments of the Bell System plant; including system relations with other wire-using utilities. In 1933 Mr. Harrison was elected vice-president in charge of operations of the Bell Telephone Company of Pennsylvania and the Diamond State Telephone Company of Delaware, with headquarters in Philadelphia, Pa. He was appointed assistant vice-president in the department of operation and engineering and transferred to New York in 1937. Mr. Harrison has a long record of active service in the Institute. Besides being president, he is at present a member of the Edison Medal and Lamme Medal committees, and is the Institute's representative on the Charles A. Coffin Fellowship and Research Fund Committee, American Engineering Council, and the John Fritz Medal board of award. Within recent years he has served as member or chairman of several other technical and general committees of the Institute.

BANCROFT GHERARDI (A'95, F'12) has retired as vice-president and chief engineer of the American Telephone and Telegraph Company, New York, N. Y. Doctor Gherardi, a past-president of the Institute, has been associated with the American Telephone and Telegraph Company and its associated companies since 1895. He was born April 6, 1873, at San Francisco, Cal., and received the degree of bachelor of science in 1891 at the Polytechnic Institute of Brooklyn, N. Y.; in 1893 he received the degree of mechanical engineer, and in 1894 the master's degree in mechanical engineering at Cornell University. Worcester Polytechnic Institute granted to him the honorary degree of doctor of engineering in 1936. In 1895 Doctor Gherardi entered the employ of the New York (N. Y.) Telephone Company, where he was engaged in various problems in planning and supervision. Four years later he became engineer of the traffic department of that company, and in 1901 was appointed chief engineer of the New York and New Jersey Telephone Company. He was assistant chief engineer of the New York Telephone Company during 1906–07. Doctor Gherardi became engineer of plant for the American Telephone and Telegraph Company in 1907, holding that position until 1918, when he was appointed acting chief engineer. He was appointed chief engineer later in the same year, and for more than 17 years he was vice-president and chief engineer of the company. He is a director of several telephone companies. Doctor Gherardi has contributed generously to the work of the Institute, having served as a manager, 1905–08 and 1914–17; vice-president, 1908–10; and president, 1927–28. He has been a member of the committees on finance, headquarters, research, and the Edison Medal and executive committees. He was chairman of the committee on Institute policy (formerly public policy) from 1930 until 1933. He has served as a member of the board of directors of the American Standards Association, United Engineering Societies, United Engineering Societies Library Board; and as Institute representative on the National Research Council, United States National Committee of the International Electrotechnical Commission, John Fritz Medal board of award, and the Charles A. Coffin Fellowship and Research Fund Committee. Doctor Gherardi was awarded the Edison Medal of the AIEE in 1932 and is a member for life. In 1923 the Japanese Government conferred upon him the emblem of the Fourth Order of the Rising Sun. He is a member of several technical societies.

H. S. WARREN (A'03, F'13) has retired as director of protection development of the Bell Telephone Laboratories, New York, N. Y., after more than 38 years of service in the Bell system, and has announced the opening of an engineering office in New York as consultant in electrical protection. Mr. Warren joined the engineering staff of the American Bell Telephone Company—which subsequently became the American Telephone and Telegraph Company—in Boston, in 1899. After being in charge of transmission development in Boston for several years he was transferred to New York in 1907 when the Boston laboratories were moved. He was appointed director of protection development in 1934, when the department of development and research of the American Telephone and Telegraph Company was merged with the Bell Telephone Laboratories. He has been a member of the Institute's committee on safety since 1915 (chairman, 1935–37) and a member of the committee on power transmission and distribution since 1925. Mr. Warren was a member of the committee on transportation during 1916–17; the Institute's alternate on the electrical committee of the National Fire Prevention Association, 1932–34; and representative on that committee during 1935–36. During 1935–36 he was also a member of the committee on low-voltage hazards of the National Safety Council and representative on the National Fire Waste Council.

JOSEPH WEIL (A'24, F'36) has been appointed dean of the college of engineering and director of the engineering experiment station of the University of Florida, Gainesville. Dean Weil was born at Baltimore, Md., July 19, 1897, and received the degree of bachelor of science in engineering at The Johns Hopkins University in 1918; in 1926 he received the degree of master of science from the University of Pittsburgh. Following his graduation in 1918 he became research assistant for the United States Naval Consulting Board, later entering the employ of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He became a member of the faculty of the University of Florida in 1921, and was appointed successively instructor, assistant professor, associate professor, becoming professor and head of the department of electrical engineering in 1930. Besides teaching, Dean Weil has served as a consulting engineer for industrial organizations, several municipalities, the State of Florida, and various governmental agencies. He is also chief engineer of the State Radio Station WRUF and director of radio projects for the United States Works Progress Administration in Florida. He served as chairman of the AIEE Florida Section from its organization in 1931 until

W. H. HARRISON

BANCROFT GHERARDI

JOSEPH WEIL

1934, and has since been acting as secretary-treasurer. For many years he was counselor of the University of Florida Branch. Dean Weil is a member of the current committee on instruments and measurements, and previously has served on the committees on sections, student branches, and education. He is secretary-treasurer of the Florida State Board of Engineering Examiners; a director of the Florida Engineering Society; and a member of the Institute of Radio Engineers, Society for the Promotion of Engineering Education, and various other societies.

Bachrach

E. C. STONE

CROSBY FIELD

Electrical World

J. F. BAILEY

E. C. STONE (M'19, F'31) recently was appointed vice-president and general manager of the Duquesne Light Company, Pittsburgh, Pa. Mr. Stone, who formerly was assistant to the president of the Philadelphia Company, Pittsburgh, was born March 8, 1882, at Charlestown, N. H., and was graduated from Harvard University with the degrees of bachelor of arts (1904) and bachelor of science (1905). He entered the service of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., in 1905, as an engineering apprentice. A year later he was appointed designing engineer in the transformer division of the engineering department. In 1911 he became associated with the Allegheny County Light Company, which two years later became the Duquesne Light Company, and remained with that organization for 20 years. In 1913 Mr. Stone organized the system operating department of the Duquesne Light Company and was system operator until 1919. In that year he was appointed assistant to the general manager, and in 1922 was made planning engineer. He was appointed manager of the systems development department in 1927 and held that position until 1931, when he was appointed assistant to the president of the Philadelphia Company. From 1925 until 1928 Mr. Stone was a member of the faculty of the school of business administration of the University of Pittsburgh, and conducted a series of courses on the economics of public utilities. In 1927 he served as a graduate lecturer at Yale University. He has contributed much to engineering literature, and presented papers to the World Engineering Congress at Tokyo, Japan, in 1929 and to the World Power Conference in 1930. Mr. Stone was a director of the Institute from 1925 until 1929 and was vice-president from 1929 until 1931.

CROSBY FIELD (A'14, F'22) has been elected president of the American Society of Refrigerating Engineers. Mr. Field was born March 12, 1889, at Brooklyn, N. Y., and received the degrees of bachelor of science (1909) and mechanical engineer (1912) at New York University and Cornell University, respectively. In 1914 he received the degree of master of science in electrical engineering at Union College. Following his graduation from Cornell he was employed by the General Electric Company, Schenectady, N. Y. After a year during which he was engaged in private consulting engineering practice Mr. Field became chief engineer for Standard Aniline Products, Inc., in 1915. He became engineering manager of the National Aniline and Chemical Company in 1919, and since 1923 he has been vice-president of the Brillo Manufacturing Company, president and director of the Flakice Corporation, and president and director of the Chemical Machinery Corporation and the Chemical Machinery Construction Co., Inc. During the World War Mr. Field was a major in the Ordnance Department of the United States Army, and now holds a commission as colonel in the Ordnance Reserve Corps. He has written many articles for technical periodicals and has presented several papers before various engineering societies. He is a member of the American Association for the Advancement of Science, The American Society of Mechanical Engineers, American Institute of Chemical Engineers, American Chemical Society, Phi Beta Kappa, and several other professional and social organizations.

J. F. BAILEY (A'29, M'35) who recently was elected vice-president and general manager of the Georgia Power and Light Company, Valdosta, formerly was manager of the northern division of the Florida Power Corporation at Ocala. Mr. Bailey was born May 6, 1890, at West Superior, Wis., and attended Carleton College. He entered the public utility business in 1914 as a service man for the Northern State Power Company at Northfield and Pine Island, Minn., where he remained until 1919. In the latter year he became construction superintendent for the Southern Minnesota Gas and Electric Company, and two years later was appointed superintendent of transmission, distribution, and operation. In 1926 he became chief engineer for the Central West Public Service Company, Omaha, Nebr. Following a brief affiliation with the Public Utilities Consolidated Corporation, Wallace, Idaho, as division manager, he became division manager of the Florida Power Corporation in 1930. Mr. Bailey was chairman of the AIEE Florida Section during 1935–36.

D. F. MINER (M'34) recently was appointed George Westinghouse professor of engineering at Carnegie Institute of Technology, Pittsburgh, Pa. Professor Miner, who will assume his new duties September 1, will act as co-ordinator for the Westinghouse Electric and Manufacturing Company's co-operative engineering plan under which a group of engineering students at Carnegie Institute of Technology will take the usual technical college course, and during the same period will receive shop and engineering experience at the Westinghouse plant. Professor Miner was born September 13, 1892, at Hazardville, Conn., and was graduated from Clark College in 1912 with the degree of bachelor of arts. He then enrolled at Worcester Polytechnic Institute, where he received the degrees of bachelor of science (1915) and electrical engineer (1917). Following his graduation he joined the Westinghouse company as assistant to the head of the electrical section of the research department. In 1927 he was made manager of the material and process engineering department, and in 1936 was promoted to the position of manager of the central engineering laboratories and standards. Professor Miner is a member of Tau Beta Pi and Sigma Xi.

R. L. THOMAS (A'19, M'26) has become executive engineer of the Consolidated Gas, Electric Light, and Power Company of Baltimore, Baltimore, Md. Mr. Thomas formerly was general superintendent of the Pennsylvania Water and Power Company, Baltimore, an organization with which he was affiliated almost continuously since 1915. He was born at Marion, Ohio, in 1887 and was graduated from Princeton University (1909) and Massachusetts Institute of Technology (1913). Mr. Thomas has written many technical articles and has presented several papers before the Institute. During 1936–37 he was chairman of the AIEE Baltimore Section.

H. V. CARPENTER (A'03, F'18) recently was awarded the honorary degree of doctor of laws by the State College of Washington, Pullman. He has been dean of the college of mechanic arts and engineering at that institution since 1915. Dean Carpenter was a vice-president of the Institute from 1930 until 1932, is at present a member of the committee on education, and was chairman of that committee during 1936–37.

F. I. LAWSON (A'34) has been appointed engineer in the Bureau of Engineering of the Chicago (Ill.) regional office of the Federal Power Commission. Previously Mr. Lawson was engaged in the engineering department of the Pacific Gas and Electric Company, San Francisco, Calif.

W. D. OLIPHANT (A'37) recently received an appointment in medical electrology at the London (England) Hospital Medical College. Mr. Oliphant, a native (1907) of Edinburgh, Scotland, and a graduate of Edinburgh University (1928) formerly was senior technical assistant for the British Electrical and Allied Industries Research Association.

R. E. CLARIDGE (A'30), formerly in the test department of Stromberg-Carlson Telephone Manufacturing Company, now is installing carrier-current systems and broadcast network equipment for C. P. R. Communications, with headquarters at Montreal, Que., Canada.

S. S. HUYETT (A'34) has become the agent for New Goldfields of Venezuela, Ltd., Ciudad Bolivar, Venezuela. Mr. Huyett previously was a shift boss for Cameron Gold Mines, Inc., Cripple Creek, Colo.

C. J. WELLS (M'37) has been appointed western regional electrical engineer for the United States Irrigation Service, with headquarters at Santa Fe, N. M. Mr. Wells formerly was chief electrical engineer for the irrigation service at Coolidge, Ariz.

L. M. NELSON (M'34) recently became superintendent of the electrical light department of the City of Rochester, Minn. Mr. Nelson formerly was superintendent of the water and light department of the City of Hastings, Nebr.

A. D. BRAGG (A'36) recently was elected vice-president of the Engineers' Club of Fresno, Calif. Mr. Bragg is sales representative for the General Electric Company, San Francisco, Calif.

L. S. C. WHITE (A'25) recently was elected president of the Gresham (Ore.) Chamber of Commerce. Mr. White is district manager of the Portland General Electric Company offices at Gresham.

Obituary

CARL GEORGE SCHLUEDERBERG (A'02, M'13) vice-president and general manager of the Ford Instrument Company, Long Island City, N. Y., died at Cleveland, Ohio, April 9, 1938. Doctor Schluederberg was born June 11, 1880, at Pittsburgh, Pa., and was graduated from Cornell University with the degree of mechanical engineer in electrical engineering in the class of 1902. He then enrolled in the graduate school of that institution, following a training course with the Westinghouse Electric and Manufacturing Company at East Pittsburgh, and received the degree of doctor of philosophy in 1908. After a year in Europe he became electrical and mechanical engineer for the United Coal Company, Pittsburgh, but remained there for only one year before becoming a commercial engineer for the Westinghouse Electric and Manufacturing Company in 1910. He remained with that company for almost 25 years, serving in various departments at the East Pittsburgh works and later as general manager of the company's plants at South Bend, Ind. and Cleveland, Ohio. Doctor Schluederberg was the author of many papers and articles on chemistry and electrochemistry. He was enrolled in the Institute as a member for life and was a member of the American Chemical Society, American Electrochemical Society, and Sigma Xi.

ERWIN R. STOEKLE (M'17, F'33) vice-president of Globe-Union, Inc., Milwaukee, Wis., died March 14, 1938. Doctor Stoekle was born June 8, 1890 at Chicago, Ill., and received the degree of bachelor of science from Northwestern University in 1911. He then enrolled as a graduate student at the University of Wisconsin and received there the degrees of master of science (1913) and doctor of philosophy (1915). Following his graduation in 1915 he became a member of the laboratory staff of the Western Electric Company, New York, N. Y., where he became engaged in research on vacuum tubes and obtained a fundamental patent on high-power metal tubes for radio transmission. Two years later he went to Milwaukee to take charge of the physical laboratory of the Cutler-Hammer Manufacturing Company. In 1922 Doctor Stoekle established the Central Radio Laboratories in Milwaukee, and three years later, when his company was merged with the Globe-Union Manufacturing Company (later Globe-Union, Inc.), he became vice-president of the new organization. He was a member of the American Physical Society, Institute of Radio Engineers, American Association for the Advancement of Science, and Phi Beta Kappa.

JOSEPH GOODMAN (A'30) chief transformer engineer, General Electric Company, Ltd., Birmingham, England, died February 22, 1938. Mr. Goodman was born June 10, 1882, at Caterby, Northamptonshire, England, and was graduated from the Electrical Standardizing, Testing, and Training Institution ("Faraday House") in 1903. Following his graduation he was employed in the testing department of The British Electric Transformer Company, Ltd., Hayes, where he remained for two years. After one year as a tester for the Marconi Wireless Telegraph Company, Ltd., he returned to The British Electric Transformer Company as chief assistant in the designing and estimating department. He remained with that company for more than 20 years, becoming chief designer in 1928. Mr. Goodman transferred his affiliation to the General Electric Company in 1929, and was made chief transformer engineer. He was a member of the Institution of Mechanical Engineers and the Institution of Electrical Engineers.

EDWARD WINFIELD JUDY (A'26) vice-president and general manager of the Duquesne Light Company, Pittsburgh, Pa., died March 24, 1938. Mr. Judy was born September 4, 1881 near Columbus, Ohio, and received his formal technical education at Ohio University. After a year devoted to construction work with the Scioto Valley Traction Company at Columbus he entered the employ of the Central Colorado Power Company. With that company, and later with Stone and Webster Engineering Corporation, he assisted in the construction of several of the large power projects in the western part of the United States. Later he became district manager of the Southern Sierras Power Company, Riverside, Calif. Mr. Judy joined the Duquesne Light Company in 1923 as superintendent of overhead lines, and was promoted to general superintendent of distribution in 1924. Early in 1927 he was appointed operating manager of the company and two years later was elected vice-president and general manager. Mr. Judy was a director of the Philadelphia Company, Duquesne Light Company, and the Equitable Sales Company. He was a past-president of the Pennsylvania Electric Association.

GEORGE ERNST HAYLER (A'06, F'31) for more than 20 years an engineer in the public utility division of Cities Service Company, New York, N. Y., died March 18, 1938, of injuries suffered when he was struck by an automobile. Born December 18, 1871, at Ann Arbor, Mich., Mr. Hayler received the degree of bachelor of science in mechanical engineering at the University of Michigan in 1894. After serving for four years as superintendent of the Electric Light and Power Company, Van Wert, Ohio, he became manager of the Gas, Electric Light, and Power Company there in 1899. Later he became an engineer for the Arnold Company, Chicago, Ill., general manager of the Spring River Park Company, Joplin, Mo., and general manager of the Empire District Electric Company, Joplin. In 1915 Mr. Hayler went to New York to become an engineer for Henry L. Doherty and Company, and later for the Cities Service Company.

RUSSELL SCHUTZ GUEFFROY (A'37) engineer with the Northwestern Electric Company at Vancouver, Wash., became separated from his party while on an attempt to climb Mt. Hood, March 27, 1938. He was not missed until the following day, when an extended search was organized and resulted in the recovery of his frozen body at the place where he had sat down to rest and had gone to sleep. Mr. Gueffroy was born August 2, 1909, at Salem, Ore., and obtained his technical education at the Oregon Institute of Technology in Portland, where he graduated in 1931. Following graduation he spent some time as assistant to the electrical engineer of the Oregon Pulp and Paper Company, Salem, before becoming associated with the Northwestern Electric Company. In addition to his work with the electric company he was teaching evening classes at Oregon Institute of Technology.

ALBERT JOHN JOSEPH MURPHY (A'19) manager of the New York Telephone Company, New York, N. Y., died February 18, 1938. Mr. Murphy was born in New York, October 28, 1895, and received his formal technical education at Pratt Institute and

Cooper Union. Mr. Murphy's entire technical career was spent in the employ of the New York Telephone Company. He became affiliated with that organization in 1916, and after gaining experience in several departments was appointed manager in 1928.

Membership

Recommended for Transfer

The board of examiners, at its meeting on April 19, 1938, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Board, V. L., vice-president and general superintendent, Public Service Company of Colorado, Denver.
Brainard, F. K., electrical engineer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Crippen, R. P., consulting electrical engineer, Ebasco Services, Inc., New York, N. Y.
Gillespie, F. M., Seattle, Wash.
Inch, S. R., president, Electric Bond and Share Company and Ebasco Services, Inc., New York, N. Y.
Knapp, P. R., superintendent, electrical distribution and transmission, The Toledo Edison Company, Toledo, Ohio.

6 to Grade of Fellow

To Grade of Member

Bates, L. W., principal engineer and project manager, Bureau of Yards and Docks, Navy Department, Washington, D. C.
Harnett, D. E., engineer, Hazeltine Service Corporation, New York, N. Y.
Hitchcock, L. W., professor of electrical engineering, University of New Hampshire, Durham.
Hunt, O. H., engineer, The Bristol Company, Waterbury, Conn.
Hutchinson, C., electrical engineer, Tennessee Public Service Company, Knoxville.
Locke, W. W., instructor in electrical engineering and superintendent of dormitory, Worcester Polytechnic Institute, Worcester, Mass.
Lubcke, C. M., associate engineer, City Light Department, Seattle, Wash.
Neher, J. H., senior engineer, Philadelphia Electric Company, Philadelphia, Pa.
O'Kelly, F. C., sales engineer, General Electric Company, Denver, Colo.
Powell, R. W., electrical engineer, Central New York Power Corporation, Potsdam, N. Y.
Robb, W. F., traffic engineer, Southern New England Telephone Company, New Haven, Conn.
Roesch, R. E., division engineer, Virginia Public Service Company, Alexandria.
Sammis, W. H., vice-president, The Commonwealth and Southern Corporation, New York, N. Y.
Von Voigtlander, F., member, engineering staff, The Commonwealth and Southern Corporation, Jackson, Mich.

14 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before April 30, 1938, or June 30, 1938, if the applicant resides outside of the United States or Canada.

United States and Canada

Ahlswede, N. E., 305 North Frances Street, Madison, Wis.
Allcorn, L. H., Jr., Hazelett Metals, Inc., Greenwich, Conn.
Anderson, W. E., Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.
Bakker, W., Public Service Electric and Gas Company Newark, N. J.
Beaudway, R. W., General Electric Company, Philadelphia, Pa.
Beers, G. S., International Business Machines Corporation, Portland, Ore.
Benesh, F. A., Southwestern Light and Power Company, Lawton, Okla.
Biele, C. E., Rockbestos Products Corporation, New York, N. Y.
Brown, A. M., Gibbs and Cox, Inc., New York, N. Y.
Cable, J. W., Consolidated Edison Company of New York, Inc., New York, N. Y.
Caskey, A. D., Public Service Company of Northern Illinois, Chicago, Ill.
Catherwood, T. E. D., Buffalo Ankerite Gold Mines, Ltd., South Porcupine, Ont., Canada.
Clay, J. A., Utah Power and Light Company, Salt Lake City, Utah.
Craig, J. C., Puget Sound Power and Light Company, Seattle, Wash.
Currie, J. D., Tennessee Valley Authority, Wilson Dam, Ala.
Delius, H. A. (Member) California and Hawaiian Sugar Refining Corporation, Ltd., Crockett, Calif.
de Westfeit, G. P., (Member) New York Quotation Company, New York, N. Y.
Eacmen, J. C., 55 Limerick Street, Gardner, Mass.
Edwards, W. F., Public Service Electric and Gas Company of New Jersey, Camden.
Foster, W. S., University of Tulsa, Tulsa, Okla.
Freeman, F. M., (Member) Consolidated Edison Company of New York, Inc., New York, N. Y.
Frehner, P. H., Pacific Electric Manufacturing Corporation, San Francisco, Calif.
Fuller, R. C., Tennessee Valley Authority, Wilson Dam, Ala.
Garceau, L., (Member) Electro-Medical Laboratory, Inc., Holliston, Mass.
Guernsey, E. D., Bell Telephone Laboratories, Inc., New York, N. Y.
Hediger, F. (Member) 70 Remsen St., Brooklyn, N. Y.
Howe, E. L., Simplex Wire and Cable Company, Philadelphia, Pa.
Humphery, S. M. (Member) Taylor-Winfield Corporation, Warren, Ohio.
Jacobs, O. R., Ohio Power Company, Lima.
Janssen, R. F., Allis-Chalmers Manufacturing Company, Philadelphia, Pa.
Jorow, E., Square D Company, Los Angles, Calif.
Kaye, R. S., Westinghouse Electric and Manufacturing Company, Boston, Mass.
Kleene, W. F., (Member) Commonwealth Edison Company, Chicago, Ill.
Knowles, P., Utilities Service Company, Allentown, Pa., Charlotte, N. C.
Leigh, J. S., RCA Manufacturing Company, Camden, N. J.
L'Hommedieu, W. P. (Member) Westinghouse Electric and Manufacturing Company, San Francisco, Calif.
Locke, W. C., 100 Gainsboro Street, Boston, Mass.
Lomasney, B. J., Reda Pump Company, Bartlesville, Okla.
McCleskey, S. L., Jr., Orangeburg Water and Light Plant, Orangeburg, S. C.
McLelland, C. C., Memphis Light and Water Division, Memphis, Tenn.
McOmber, M. W., Colt's Patent Fire Arms Manufacturing Company, Hartford, Conn.
Miller, F. E., San Joaquin Light and Power Company, Santa Maria, Calif.
Miller, G. H., Consolidated Edison Company of New York, Inc., Brooklyn, N. Y.
Minzner, W. R., 42 Baremeadow Street, Methuen, Mass.
Moes, G., (Member) Hamilton Sterling Electrical Company, Ltd., Hamilton, Ont., Canada.
Muniz, R. (Member) Brooklyn Technical High School, Brooklyn, N. Y.
Neely, T. H., Bell Telephone Laboratories, In New York, N. Y.
Painter, J. H., New Jersey Bell Telephone Company, Newark.
Potts, H. M., Public Utility Districts, Tacoma, Wash.
Pratt, L. W., Hydro-Electric Power Commission of Ontario, Toronto.
Raynes, R. K. (Member) 98 Church Avenue, Fairville, N. B., Canada.
Renner, H. H., 2210 University Avenue, New York, N. Y.
Richmond, L. W., Chesterland, Ohio.
Schlesinger, J. P., Jr., Bethlehem Steel Company, Sparrows Point, Md.
Schoneld, M. F., Indiana Service Corporation, Ft. Wayne, Ind.
Searight, F. H., Allis-Chalmers Manufacturing Company, Milwaukee, Wis., San Francisco, Calif.
Simpson, W. A., Timken Roller Bearing Company, Canton, Ohio.
Skyllingstad, D. E., United Light and Power Engineering and Construction Company, Kansas City, Mo.
Smith, M. J., Houston Lighting and Power Company, Houston, Texas.
Smith, R. A., Delavan Engineering Company, Des Moines, Iowa.
Smith, V. A., Reda Pump Company, Bartlesville, Okla.
Starkweather, H. C., (Member) United States Army, Baltimore, Md.
Stratton, M. E., Carnegie-Illinois Steel Company, Ind.
Stroud, R. A., Southwestern Light and Power Company, Lawton, Okla.
Styner, P. M., (Member) The Empire District Electric Company, Joplin, Mo.
Sumner, M. R., (Member) Federal Power Commission, Washington, D. C.
Tuttle, D. F., Jr., Bell Telephone Laboratories, Inc., New York, N. Y.
Well, A. F., Southern Indiana Gas and Electric Company, Evansville, Ind.
White, A., Spencer Thermostat Company, Attleboro, Mass.
Wortman, H. B., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Wright, R. F., General Electric Company, New Orleans, La.

Total, United States and Canada—71

Elsewhere

Bennett, R. S., (Member) Thomas Firth and John Brown, Ltd., Sheffield, England.
Ely, E. S., Southern Railway England, Southampton, England.
Krishnaswami, A. C. K., in care of Messrs. Seshasayee Bros., Ltd., Tennur, Trichinopoly, South India.
Kwatra, J. N., Siemens (India), Ltd., Lahore, India.
Lewis, H. A., British Broadcasting Corporation, Surrey, England.
Ryan, E. R., University College, Galway, Ireland.
Sundararaman, R., Crompton Engineering Company (Madras), Ltd., Madras, South India.
Tao, S., Tokyo Electric Company, Ltd., Kawasaki, Japan.
Yleans, G. E., (Fellow) Ma-ao Sugar Central Company, Inc., Occidental Negros, P. I.

Total elsewhere—9

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Society Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

COMMISSION INTERNATIONALE de l'ÉCLAIRAGE, 9th Session, Berlin and Karlsruhe, July 1935. RECUEIL des TRAVAUX et COMPTE RENDU des SÉANCES. Published under the direction of the National Physical Laboratory of Teddington, England. Cambridge, England, University Press, 1937. 679 pages, illustrated, 10 by 6 inches, cloth 20s. Contains reports of the proceedings of the ninth meeting of the International Lighting Commission, its official recommendations and also the reports presented by various technical committees. Discusses trends and developments in many directions: photometry; the lighting of streets, factories, and mines; aviation and automobile lighting; traffic signals; and artificial daylight. The reports are in English, French, or German, with brief summaries in all three languages.

TECHNICAL MATHEMATICS, 3 volumes. By H. M. Keal and C. J. Leonard. Second edition. New York and London, John Wiley & Sons, 1938. Volume 1, 246 pages; volume 2, 277 pages; volume 3, 314 pages, illustrations, 7 by 5 inches, cloth, $1.25 each volume. The three volumes of this secondary or trade-school textbook treat respectively the subjects of algebra, geometry, and trignometry.

NATIONAL ELECTRICAL CODE HANDBOOK. By A. L. Abbott. 4 edition. New York and London, McGraw-Hill Book Company, 1937. 561 pages, illustrations, 8 by 5 inches, leather, $3.00. Discusses the provisions and practical application of the National Electrical Code.

DEUTSCHES MUSEUM Abhandlungen und Berichte, Jg. 9, Heft 5. Die ENTWICKLUNG der TELEGRAPHIE auf DRAHTLEITUNGEN, by E. Feyerabend. Berlin, VDI-Verlag, 1937. 145 pages, illustrated, 8 by 6 inches, paper, 0.90 rm. A brief account of the evolution of telegraphy in Germany.

(The) ADMINISTRATION of FEDERAL GRANTS to STATES. By V. O. Key, Jr. Published for the Committee on Public Administration of the Social Science Research Council by Public Administration Service, Chicago, 1937. 388 pages, tables, 9 by 6 inches, cloth, $3.75. One of a series of studies of the administrative problems of the social security program. Limited to an examination of administrative practices, policies, and problems from several federal agencies and jointly financed state activities.

Transactions
Papers and Discussions Comprising Pages 227–294 of the 1938 Volume

A Carrier Telephone System for Toll Cables

By C. W. GREEN MEMBER AIEE E. I. GREEN MEMBER AIEE

Synopsis: A new 12-channel carrier telephone system for existing cables is described. This system, which incorporates a number of interesting departures from the previous carrier art, is now being manufactured in considerable quantities to meet increased traffic requirements.

AN IMPORTANT advance in the art of carrier telephony has been made by the development of a new 12-channel system, known as the type *K*, for toll telephone cables of existing type. It is applicable both to cables installed underground, and also to aerial cables, for which the wide range of temperature variation introduces quite difficult transmission problems. Field trials on cables previously installed between Toledo and South Bend have been successful, and the system is now being manufactured to meet field demands.

This new development is an outgrowth of the experiments at Morristown, N. J., described by Messrs. Clark and Kendall before this Institute in 1933,[1] and the essential principles of the new system were included in those experiments. The earlier work dealt, however, with cable specially designed for carrier operation, and only underground cable was experimented with. As that work drew to a close, it became clearer that because of general economic conditions several years would elapse before the Bell System would require any substantial increase in toll facilities. Hence this early system was not put into commercial form, but work was continued to determine the extent to which carrier could be applied to existing cables, of which more than 15,000 miles were available for such use. Serious problems of crosstalk at high frequencies had to be reckoned with. A more serious problem, however, was that of maintaining stability of transmission, since with aerial cable, which comprises about two-thirds of the existing cable mileage, the total variation in attenuation, due to temperature variation, is about three times that for underground cable, and the rate of variation not infrequently is several hundred times as great.

In spite of these and other difficulties, the capabilities of the present system go far beyond those of previous systems. As a development objective the maximum length was taken as 4,000 miles, with as many as five separate systems linked together. On the basis of results thus far obtained it is expected that for these exacting conditions the performance with respect to crosstalk, noise, transmission stability, width of voice band, and other characteristics will equal or exceed that of previous facilities for much shorter distances.

Superior performance has been achieved without material effect on the cost of the system. For distances of a few hundred miles, on moderately heavy traffic routes, it will provide telephone circuits at a much lower cost than previous facilities. The minimum distance for which the system will be useful may be less than 100 miles.

Interesting features of the new system are:

1. A line of very high attenuation, requiring high-gain repeaters spaced at approximately 17-mile intervals. This would mean, for the maximum distance for which the system is designed, more than 200 repeaters in tandem.

2. The use in the repeaters of the negative feedback principle of amplification to obtain the requisite stability and freedom from modulation.

3. Small auxiliary repeater stations, established between existing voice-frequency repeater stations, housing equipment which can be left for considerable periods of time without attention.

4. A system of transmission regulation whereby huge variations of attenuation, differing at each frequency, are automatically equalized to a high degree of accuracy.

5. New methods of crosstalk and noise reduction. Small adjustable mutual inductance coils are connected between carrier pairs to balance out the crosstalk. The noise is kept at an extremely low level to permit the high gains.

6. Channel terminal equipment designed so that it may be used in other types of carrier systems, thus simplifying development and manufacture, and facilitating the interconnection of different types of systems.

7. Speech bands considerably wider than those of existing facilities. The increase is obtained by spacing the channels at uniform 4,000-cycle intervals, and employing channel band filters containing quartz-crystal elements.

8. High speed transmission, which is of considerable value from the standpoint of minimizing delays and echoes.

A general description of the system is presented herein, and the different parts are taken up in greater detail in other papers.

Paper number 37-136, recommended by the AIEE committee on communication, and presented at the AIEE winter convention, New York, N. Y., January 24–28, 1938. Manuscript submitted October 29, 1937; made available for preprinting December 18, 1937.

C. W. GREEN is carrier telephone engineer with the Bell Telephone Laboratories, Inc., New York, N. Y., and E. I. GREEN is in the transmission development department of the same company.

1. For all numbered references, see list at end of paper.

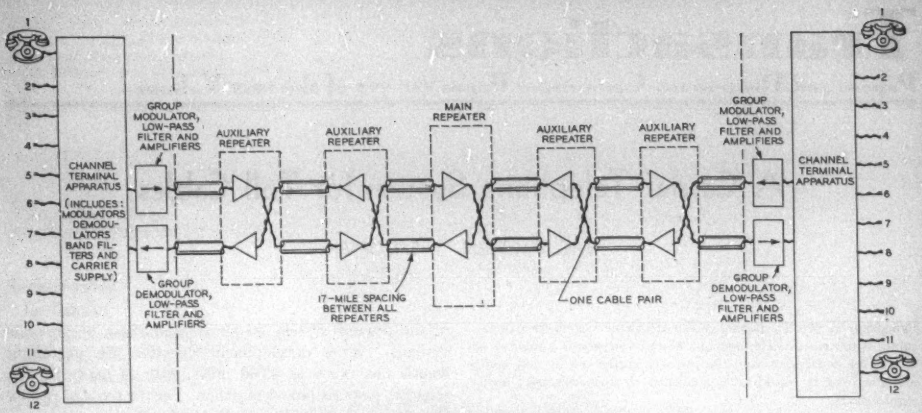
CHANNEL TERMINAL APPARATUS (INCLUDES: MODULATORS DEMODULATORS BAND FILTERS AND CARRIER SUPPLY)
GROUP MODULATOR, LOW-PASS FILTER AND AMPLIFIERS
GROUP DEMODULATOR, LOW-PASS FILTER AND AMPLIFIERS
AUXILIARY REPEATER
AUXILIARY REPEATER
MAIN REPEATER
AUXILIARY REPEATER
AUXILIARY REPEATER
GROUP MODULATOR, LOW-PASS FILTER AND AMPLIFIERS
GROUP DEMODULATOR, LOW-PASS FILTER AND AMPLIFIERS
CHANNEL TERMINAL APPARATUS
17-MILE SPACING BETWEEN ALL REPEATERS
ONE CABLE PAIR

Figure 1. Schematic of type K system

General Considerations

The type *K* system, whose elements are illustrated schematically in figure 1, operates on a "four-wire" basis, using the same frequency range, but different electrical paths, for opposite directions of transmission. Thus it differs from open-wire carrier systems, for which the line is not suitable for four-wire operation, and which therefore require complicated and expensive filters to separate the different frequency bands used for transmission in opposite directions. A high degree of shielding between the two cable paths is necessary to avoid the effects of near-end crosstalk, which would be serious because of the large level differences existing at the repeaters and the terminals. On routes where two or more cables exist, such shielding is obtained by employing two separate cables, with transmission in one direction only in each section of cable. On single cable routes, a similar arrangement is obtained by adding a small cable. Where there is no cable, two small cables may be provided. Also satisfactory shielding between the carrier pairs used for opposite directions of transmission has been obtained in short experimental lengths of cable by the use of a layer shield.

Frequency Allocation

In contrast to the original Morristown system which gave nine one-way channels per pair in the range from 4 to 40 kilocycles, the type *K* system has 12 channels in the range from 12 to 60 kilocycles. As shown in figure 2, the frequency range of the type *K* system is roughly

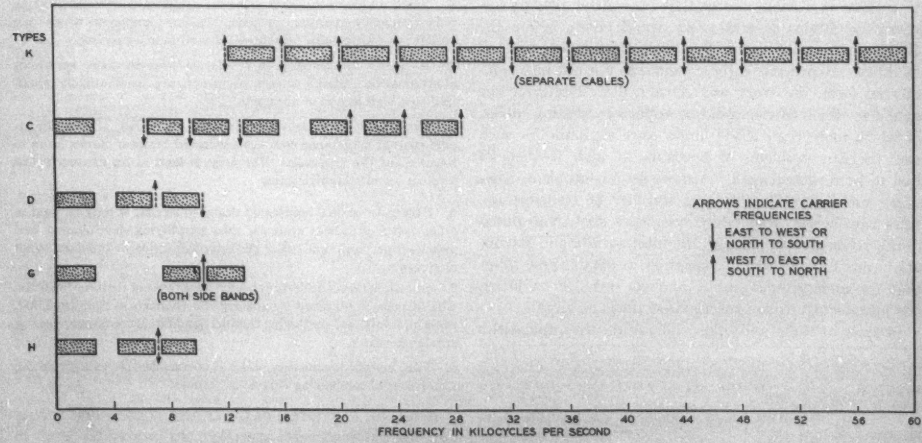

Figure 2. Frequency allocation of carrier telephone systems

double that of preceding open-wire carrier systems.[3] The choice of 12 and 60 kilocycles, respectively, as the lower and upper frequency limits was governed by economic considerations, and there is nothing technically insurmountable either in going to considerably higher frequencies or in utilizing the lower frequency range, which is now idle except for the use of the d-c path for purposes of transmission regulation and fault location. Important factors influencing the selection of the upper frequency are the crosstalk, which depends on the number of pairs utilized for carrier in one cable and the extent to which special crosstalk balancing means are used, and the attenuation, which largely controls the spacing between repeaters. Factors affecting the lower limit include the difficulty of maintaining accurate transmission regulation over the whole frequency range, and the design of the repeater, which becomes harder as the ratio of maximum to minimum transmitted frequency is increased.

The frequency range between 12 and 60 kilocycles accommodates 12 speech channels, each occupying a gross band of four kilocycles. The single-sideband method of transmission is employed, with carrier frequencies suppressed. The choice of a group comprising 12 channels was influenced not alone by the requirements of the type *K* system itself but also by those of other broad-band systems. From the earliest stages of the broad-band development it was recognized that there would be considerable advantage from the standpoints of flexibility of interconnection, of minimum development effort, and of large scale production of equipment units, if the designs of different broad-band systems could be so co-ordinated as to enable the same design of channel terminal equipment to be employed for each. A common 12-channel terminal unit developed for this purpose is used in the type *K* system.

The spacing of the channels in broad-band systems is important from the standpoint of the channel selecting circuits and the width of the derived voice circuit. As discussed in a recent article, a uniform 4,000-cycle interval has been adopted for the different channels of all broad-band systems.[4] The speech band width obtained with this spacing is in keeping with recent improvements in telephone instruments and other parts of the telephone plant. Over-all transmission-frequency characteristics for a single link and a five-link connection are shown in figure 3.

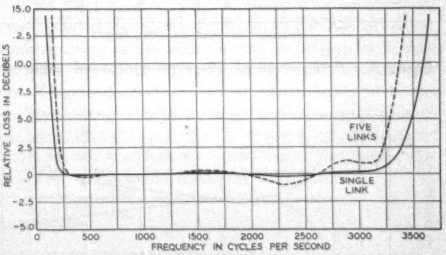

Figure 3. Transmission-frequency characteristics of over-all circuit

Cable Attenuation

The type *K* system is designed to be applied to the number 19 American Wire Gauge (0.9 millimeter) pairs commonly found in existing cables. (The Morristown system used 16-gauge pairs.) Because the conductors are small and closely spaced, with paper and air dielectric, the attenuation of a nonloaded 19-gauge pair at the frequencies involved is inherently high, as will be seen from figure 4. Because of the high attenuation, the repeaters must be placed much closer together than is necessary for voice-frequency cable circuits. Fortunately this effect is partly offset by the fact that it is possible, as discussed later, to use higher gains in the carrier repeaters.

The cable pairs exhibit the rise in attenuation with frequency which is familiar in most transmission circuits. This effect is brought about largely by the increase in conductor resistance, due to skin effect, and the increasing dielectric losses. More important than this, however, is the fact that the resistance of the wires and the other "constants" of the cable pair undergo variations with temperature, which in turn affect the attenuation. The magnitude of the result for a representative nonloaded 19-gauge cable pair is illustrated by the curves of figure 4, which show, respectively, the attenuation for an average temperature, assumed to be 55 degrees Fahrenheit, and for 0 and 110 degrees Fahrenheit. The latter values, often taken as the extremes of annual variation for an aerial cable, are in fact frequently exceeded. One reason for this is that when the sun is shining directly on an aerial cable, it may assume a temperature from 15 degrees to 25 degrees above that of the ambient air. The range of temperature variation (and attenuation variation) for an aerial cable may be half as much in one day as in an entire year. For an underground cable, changes of temperature occur quite gradually and the total annual variation is about one-third of that for an aerial cable.

These relations between the attenuation of a cable pair and the frequency and temperature are of fundamental importance in the design of the type *K* system. First of all, since the attenuation at 60 kilocycles is about four decibels per mile, the total attenuation for a cable circuit of the length used in designing the type *K* system, i. e., 4,000 miles, would be approximately 16,000 decibels. This must be offset by a corresponding gain.

In the next place, differences in the attenuation at the different frequencies would, if uncorrected, become so great that signals of the less attenuated channels would overload the repeaters, while those of the more attenuated channels would drop down into the noise region. Hence, each repeater must be given a gain-frequency slope which is complementary to the attenuation slope of the line.

Finally, the changes of transmission due to temperature variations and other causes must be compensated so precisely that the net variation in each channel is held within very narrow limits. The method of doing this is explained later. Here it is interesting merely to consider the magni-

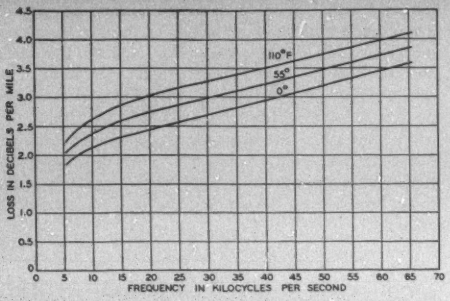

Figure 4. Attenuation of 19-gauge nonloaded cable pair

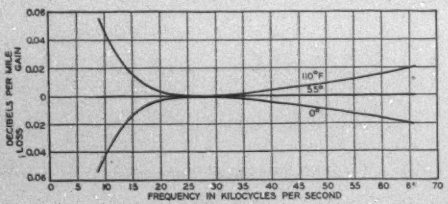

Figure 5. Twist characteristics of 19-gauge nonloaded cable pair

tude of the problem. For the top channel, assuming a 4,000-mile circuit, the annual variation in attenuation of an aerial cable pair might be approximately 2,000 decibels. The systems thus far installed have, of course, been limited to much shorter distances than this.

Even if the change of attenuation with temperature were related to frequency by a simple law, correct compensation over the frequency range would be far from easy. To a casual inspection the differential between any two curves of figure 4, for example those for 55 and 110 degrees Fahrenheit, will not appear serious. This differential, which becomes very large for a long circuit, is, however, a complicated function of the frequency.

The attenuation differential with temperature can be considered as made up of two components, one which is independent of frequency and another which varies with frequency. The former component, which is much the larger, requires a gain adjustment which is uniform or flat over the frequency range of the system. The latter component is frequently referred to as the "twist." For the range from 12 to 60 kilocycles, the maximum change of attenuation with temperature occurs near 28 kilocycles. Hence this frequency has been used as a datum point in determining the twist. The shape of the twist component is apparent from figure 5, which shows the net loss per mile at temperatures of 0 and 110 degrees Fahrenheit, assuming that the attenuation has been equalized so as to obtain a flat characteristic at 55 degrees Fahrenheit, and that the gain is then adjusted so as to hold the transmission constant at 28 kilocycles as the temperature varies. Although the twist is small enough so that it need not be corrected at each repeater, it is too large to be allowed to accumulate over a very long distance.

Crosstalk

As noted above, crosstalk between opposite directions of transmission is avoided by using two separate cables (or shielded compartments in the same cable). To prevent

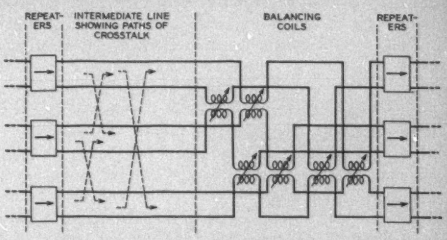

Figure 6. Method of balancing out crosstalk

crosstalk in offices, special measures are employed. There remains the problem of "far-end" crosstalk between pairs in the same cable which transmit in the same direction. The pairs are packed closely together, and substantial crosstalk occurs between them because of small departures from symmetry and slight imperfections of twisting. However, by abandoning the use of phantoms and by connecting small adjustable mutual inductance coils between each carrier pair and every other carrier pair, sufficient crosstalk reduction is obtained to permit transmission up to 60 kilocycles on a substantial number of pairs.[4] The scheme is illustrated in figure 6.

In the original Morristown cable, the crosstalk was reduced in part by separating the 16-gauge carrier pairs from one another by 19-gauge quads which served as spacers. With existing cables, however, the use of spacers would be impracticable since this would require resplicing the cable at every joint, and therefore reliance must be placed largely on balancing. Since the number of combinations to be balanced increases approximately as the square of the number of pairs employed for carrier, the number of balancing coils required for even a moderate complement of carrier pairs becomes quite large. With 40 carrier pairs, for example, the number of coils required is 780. The balancing coils are mounted on panels as shown in figure 7 and are connected together in a crisscross arrangement. Each repeater section is balanced separately, the balancing panels being located in the repeater station.

Other measures are necessary to supplement this balancing technique. To reduce the crosstalk coupling, and also to average the transmission characteristics of different pairs, the carrier pairs in different quads of an existing cable are respliced about every mile so as to approach random splicing. The crosstalk coupling between the two sides of a quad is reduced by test splicing at the middle of a repeater section and the quads are split at repeater points.

In a new cable, of course, the desired splicing arrangements are introduced at the time of installation. The carrier pairs are also transposed from one cable to the other as indicated in figure 1. This avoids interaction crosstalk that would take place, through the medium of the voice-frequency pairs, between the high level carrier outputs on one side of a repeater station and the low level inputs on the other side. There is, of course, a similar effect between carrier pairs at any point in a repeater section. This is much less serious since no level difference is involved, but it does tend to limit the effectiveness of the balancing over a range of frequencies.

Reflections resulting from impedance irregularities reverse the direction of propagation and therefore produce far-end crosstalk from near-end crosstalk. This crosstalk cannot readily be balanced out over a range of frequencies. To avoid it, it is necessary that the impedances of successive lengths of cable pair be substantially uniform and also that the impedance of the equipment be closely matched to the characteristic impedance of the cable pair.

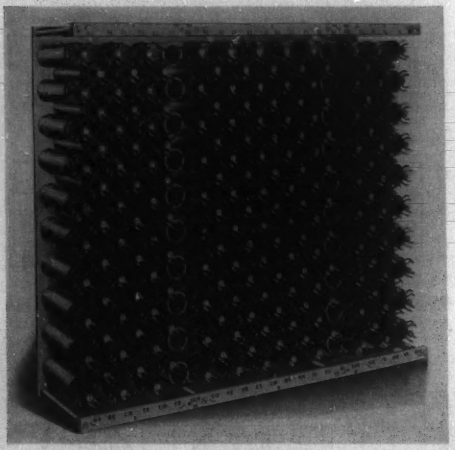

Figure 7. Crosstalk balancing panel

Noise

The cable pairs are fairly well protected by the lead sheath from external electrical disturbances. However, high-frequency noise originating in the voice-frequency repeater stations due to relay operation, etc., would, unless prevented, enter the cable over the voice-frequency pairs and thence would be induced in the carrier pairs. Such noise would be excessive at the low-level carrier inputs. It is avoided by connecting, in each voice-frequency pair in the "low-level" cable on each side of a voice-frequency repeater station, a coil which supresses longitudinal noise currents. Similarly, it is necessary to keep high-frequency noise from entering the cable where open-wire pairs tap into it and frequently also where branch cables are connected. For this purpose simple noise-suppression filters are employed. With these and other measures the noise on the carrier pairs can, at the highest frequencies where the amplification is greatest, be brought within a few decibels of the basic noise due to thermal agitation of electricity in the conductors themselves.

Velocity of Transmission

Voice waves travel through loaded cable circuits at from 10,000 to 20,000 miles per second, the higher speed being used for the longer circuits. On very long connections, even if echo suppressors are employed this velocity results in transmission delays which introduce difficulties in conversation.[5] The use of nonloaded conductors for the type *K* systems results in an over-all velocity of transmission of about 100,000 miles per second, a speed so high that such difficulties are greatly reduced and satisfactory telephone conversations are possible over the longest distances for which connections may be required.

Repeaters

Since the noise level in the cable circuits can be made quite low, the carrier currents may be permitted to drop to levels below those used on voice-frequency circuits or on open-wire carrier circuits, and the repeaters may have higher gains. In the cable carrier system the noise has been so reduced that the level of the top channel at the repeater input may on the average be dropped about 60 decibels below the voice level at the transmitting switchboard. The amplifier gains at the top frequency range from about 50 to 75 decibels and the output level of each of

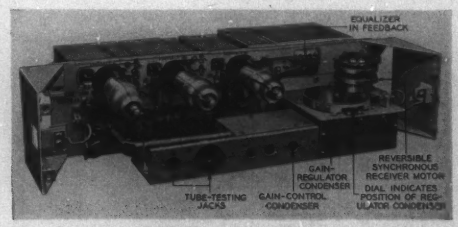

Figure 8. Line amplifier

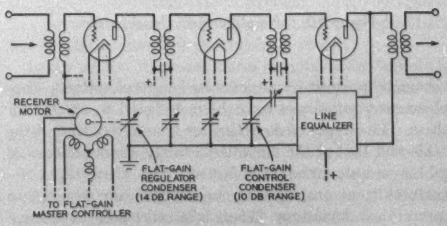
RECEIVER MOTOR
LINE EQUALIZER
FLAT-GAIN REGULATOR CONDENSER (14 DB RANGE)
FLAT-GAIN CONTROL CONDENSER (10 DB RANGE)
TO FLAT-GAIN MASTER CONTROLLER

Figure 9. Schematic of line amplifier

the 12 channels is about ten decibels above that at the switchboard. The average repeater spacing is about 17 miles.

The tube which was developed for the gain stage of the amplifier is a pentode with indirect heater. The heater requires a potential of ten volts and a current of 0.32 ampere and the plate, 150 volts. The tube in the power stage is similar in type but requires a heater current of 0.64 ampere at ten volts. With this power tube a feedback of about 40 decibels has been found to provide a satisfactory reduction of inter-channel modulation.[6] Both tubes were designed to have long life with very reliable performance.

Description of Amplifier

Each repeater comprises two amplifiers of the type illustrated in figure 8. A schematic diagram of the amplifier circuit is shown in figure 9. Three stages with impedance coupling are used and the feedback circuit is connected between the plate circuit of the last tube and the grid circuit of the first. The amount of gain and the slope of the gain-frequency characteristic are controlled by the condensers and line equalizer in the circuit.

The line equalizer has the same attenuation slope as the line. In the introduction of this equalizer in the feedback circuit careful attention to phase-shift requirements was required. Four types of equalizers are available, for different repeater spacings, to compensate for the cable distortion which occurs at a temperature of 55 degrees Fahrenheit, additional means being provided to compensate for variations which occur as the cable temperature swings away from this value. The solid curve of figure 10 shows a repeater gain characteristic with one of these equalizers in the feedback circuit.

The correction introduced by the line equalizers is subject to errors which, although small at each repeater point,

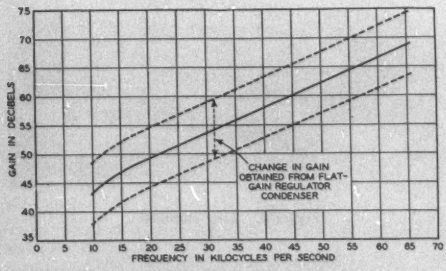

Figure 10. Amplifier gain characteristics

become important for a moderate length of system. Supplementary equalizers have been designed to correct for these. Two types of deviation are considered, that of the cable and that of the amplifier. As the characteristics of cables manufactured at different times show slight departures from one another, two shapes are required to correct their deviations. There is one corrector for concave deviations and another for convex. The amplifier requires but one type of correction. The characteristics of these equalizers are shown in figures 11 and 12. The equalizers for amplifier deviations are used about every tenth repeater and those for the cable deviations at distances of 300 to 400 miles. At normal temperature (55 degrees Fahrenheit), the correction applied by these networks will, for a 500-mile system, result in a frequency characteristic which is flat to within less than two decibels over the range from 12 to 60 kilocycles. For a longer circuit further corrective measures will be provided.

Regulation for Temperature Effects

The method adopted for controlling the repeater gain to compensate for temperature changes is similar to that which has been found satisfactory for voice-frequency cable circuits. This is the pilot-wire method in which a pair of cable conductors extending over the section to be regulated forms one arm of a Wheatstone bridge. This bridge is designed for automatic self-balancing and the mechanical motion required for establishing the balance has been made to adjust the gain of the amplifiers. The d-c resistance of the pilot wire gives an accurate indication of the temperature of the carrier pairs, which determines their attenuation to a close approximation. The mo-

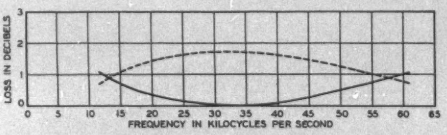

Figure 11. Characteristics of cable deviation equalizers

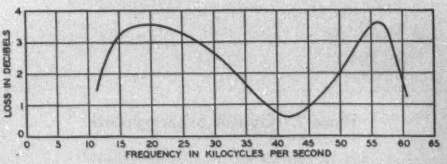

Figure 12. Characteristics of amplifier deviation equalizer

tion of the bridge mechanism is communicated to the repeater amplifiers by means of self-synchronizing motors, a master motor being associated with the bridge and an individual motor with each amplifier.

With aerial cable a flat gain correction must be made at every repeater. With underground cable the flat gain correction may be omitted at some repeater points. Figure 13 shows a master controller with its galvanometer, driving motor, and self-synchronizing motor. The air condenser in the feedback circuit of figure 8 makes this correction. The small self-synchronizing motor which may be seen in this figure is geared to the condenser and it moves the air condenser in accordance with the motion of the master motor. The resulting change in repeater gain is virtually the

same for all frequencies in the transmitted band. In figure 10 the repeater gain is plotted against frequency for three angular positions of the condenser.

As was mentioned earlier, an additional correction for the residual effect or "twist" is required about every six repeaters to supplement the flat gain adjustment. This distortion is a function of frequency and has been found to vary from cable to cable. A network whose characteristics are shown in figure 14 has been developed to meet

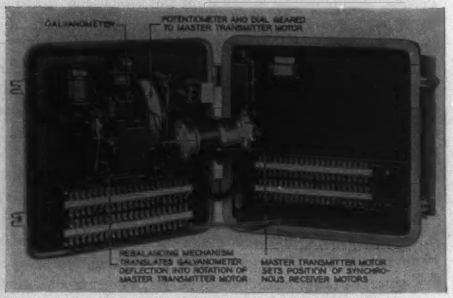
GALVANOMETER
POTENTIOMETER AND DIAL GEARED TO MASTER TRANSMITTER MOTOR
REBALANCING MECHANISM TRANSLATES GALVANOMETER DEFLECTION INTO ROTATION OF MASTER TRANSMITTER MOTOR
MASTER TRANSMITTER MOTOR SETS POSITION OF SYNCHRONOUS RECEIVER MOTORS

Figure 13. Flat gain master controller

this condition. Certain fixed resistances in the network are selected to correspond to the length and twist characteristic of the cable section considered. A variable resistance in the network is adjusted automatically using a control similar to the flat gain regulator. Figure 15 gives the transmission characteristics of a 150-mile regulator-controlled circuit under two temperature conditions.

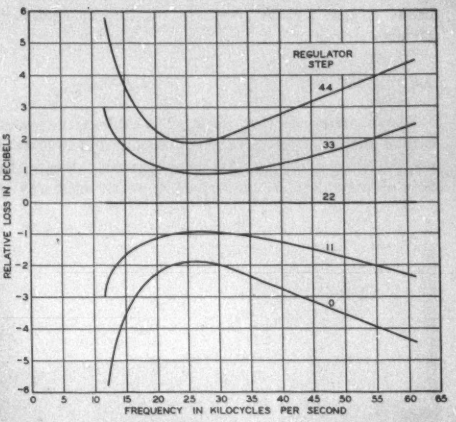

Figure 14. Characteristics of twist regulator networks

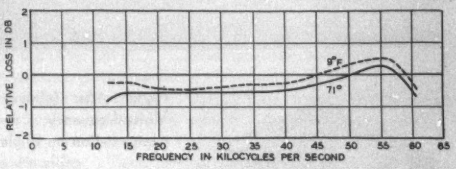

Figure 15. Over-all transmission-frequency characteristic of 150-mile line

Auxiliary Repeater Stations

Cable carrier systems are expected to be used largely on existing toll-cable routes which now carry voice-frequency circuits. The average spacing of the stations housing the voice-frequency repeaters on these routes is about 50 miles. The same buildings with their power plants will also care for the cable carrier repeaters. Since the maximum spacing for the carrier repeaters is about 19 miles, additional carrier repeaters must be provided at intermediate stations (two is the usual number). The various design features of the equipment to be located in these stations have been made the subject of extensive development work and field tests. These stations are designed to function with a minimum of attention and are visited at intervals for routine testing work or as required by some emergency, but resident maintenance forces are not planned for them. The present equipment is expected to be suitable not only for auxiliary stations on existing cable routes but also for cases where a greater spacing than 50 miles between the attended stations may be desired on new routes.

A voice-frequency repeater station for a single cable and a cable carrier auxiliary station are shown to approximately the same scale in figures 16*a* and 16*b*, respectively. Many of the existing voice-frequency stations are even larger than that shown in figure 16*a*. The auxiliary building shown in figure 16*b* has about 600 feet of floor space with a ceiling height sufficient to take care of 11-foot six-inch relay racks. This building will house 100 repeaters with necessary auxiliary equipment, thus providing ultimately for a total of 1,200 carrier circuits. The interior of a typical auxiliary station is shown in figure 17.

The main power plant for the repeaters consists of a 152-volt storage battery, which is continuously floated across a grid-controlled rectifier fed from the 60-cycle power mains. The voltage of the entire battery applies the plate voltage for the tubes. Each amplifier requires about 22 volts for the tube heaters and this is obtained by dividing the battery into seven sections, each section supplying several amplifiers in parallel. Additional power supplies of 55 volts alternating current and 140 volts direct current are required for the regulator system.

In the station, there are alarm circuits, which signal the nearest attended office if trouble develops. There are alarms for blown fuses, high or low battery voltages, power failures, etc. A telephone order wire to the nearest attended station is provided for the maintenance force.

In addition to the line amplifiers with their regulating equipment, there are racks mounting the crosstalk-balancing coils. There are also sealed terminal units between the outside cable or the balancing units and the office

cable. These furnish access to the line or equipment through jacks.

Terminals

The minimum distance over which a cable carrier system can be operated economically is determined in large measure by the cost of the terminal apparatus. Hence, the field of usefulness of the system is greatly increased by keeping the terminal cost as low as is consistent with satisfactory performance. Numerous developments during the past few years in connection with modulation, filtering, and methods of carrier supply have all contributed materially toward this end. At the same time, the standards of performance have not only been maintained, but in many respects substantially improved.

Figure 16a (above). Voice-frequency repeater station on single cable route

Figure 16b. Auxiliary cable carrier repeater station

Channel and Group Modulation

In the design of the terminals for the type *K* system, a number of circuit arrangements were considered, the final choice being influenced to a considerable extent by the conditions imposed upon the filters. As noted above, the desirability of using the channel terminal equipment in other broad-band systems such as those for open wire or coaxial cable was also an important factor. The circuit arrangements selected have a first stage of modulation which raises the voice frequencies of the 12 channels up to a range of 60 to 108 kilocycles. This range is favorable to the use of crystal type band filters,[7] which have transmission characteristics superior to the coil and condenser type and seem to be no more costly. For the type *K* system, a single stage of group modulation shifts the frequencies to the range required on the line, 12 to 60 kilocycles and a similar stage at the receiving end returns them to the 60 to 108-kilocycle range. Other carrier systems will also use the 60 to 108-kilocycle channels and by group modulation shift them to the desired position in the frequency spectrum.

The band filter occupies a space on the relay rack equal to one-eighth of that required by the coil and condenser type which was used in the earlier model of this system. Its attenuation characteristic in the transmitting region is flat to within one decibel over a range of about 3,100 cycles. Immediately outside of this range the attenuation rises very rapidly, thus permitting very efficient use of the frequency spectrum.

Another new device on the terminal is the copper-oxide unit used in the modulating process. These units are expected to show a stability of the same order as that of coils and condensers, and require practically no maintenance as compared to vacuum tubes.

The translation of the channels from the 60 to 108-kilocycle range to the position required for cable carrier, 12 to 60 kilocycles, is made by a stage of group modulation. A copper-oxide group modulator is used and a carrier frequency of 120 kilocycles. The reverse of this process in a similar group demodulator at the receiving end steps the frequency back to its original range, 60 to 108 kilocycles. These processes of modulation take place at points of low energy level in the circuit with a comparatively high level of carrier, so that the interchannel crosstalk which results from unwanted products of modulation is unobjectionable. Low-pass filters are inserted after the group modulator and demodulator, and amplifiers with

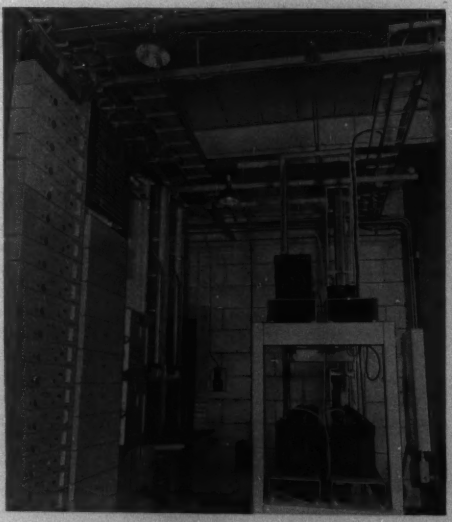

Figure 17. Interior of auxiliary repeater station

flat gain characteristics are supplied to raise the levels of the output currents of the group modulators or demodulators.

Carrier Supply

The carrier frequencies which are required at a terminal are obtained from the harmonics of a base frequency. The carrier supply system is common to as many as ten systems in one office. This simplification was made possible by the selection of the channel frequencies as multiples of a base frequency, four kilocycles being chosen for this system. This base frequency is produced by an oscillator in which the control element is a tuning fork, the whole unit being designed to have the necessary output and frequency stabilities. The output of the oscillator is amplified and fed to a circuit which produces the desired harmonics. All of the carrier frequencies which are required for the different channels as well as for group modulation and demodulation are obtained from these harmonics. A small coil with a permalloy core is the important agent in this process.[8]

Failure of the four-kilocycle supply, or failure of the 120-kilocycle supply used for group modulation, would cause failure in the channels of all systems operating from this supply. Provision is made for such a contingency by an emergency carrier supply which is automatically switched into service when the regular supply fails. This reserve source duplicates all of the parts of the regular supply, four-kilocycle fork, amplifier, harmonic producer, and amplifier for the 120-kilocycle carrier.

Assembly

The different panel units which make up the terminal of a type *K* system are assembled on a functional basis with similar panels of other *K* systems, the channel modulator-demodulator panels in one bay, the carrier supply in a second, the group modulator and demodulator in a third, etc. The compactness of the equipment makes it possible to mount the modulators and demodulators for 18 channels on one 11-foot six-inch bay 19 inches wide.

Signaling

The same type of ringdown signaling equipment is used with the channels of this system as with the voice-frequency toll circuits. A 1,000-cycle tone, interrupted 20 times per second, is impressed on a channel terminal, modulated, and transmitted over the carrier system in the allotted channel band. At the far end, it is demodulated to operate the receiving end of the standard voice-frequency receiving circuit, or to be transmitted along an extended voice-frequency circuit to its terminal.

Telegraph and Program Applications

Voice-frequency telegraph can be superposed on any of the carrier channels as is now done on the three-channel open-wire systems. Equipment is being developed to superpose a program channel on the cable carrier system. This will be done by devoting to the program circuit the frequency space occupied by two of the four-kilocycle speech bands.

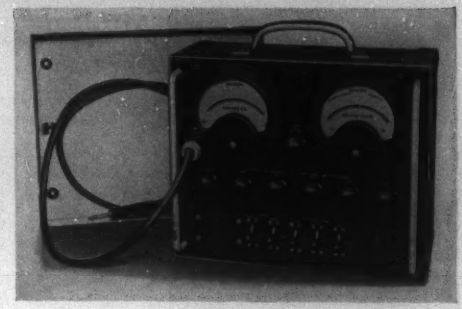

Figure 18. Vacuum tube test set

System Maintenance

Arrangements are provided whereby the tubes may be tested on a routine basis as has been done in voice-frequency practice. The amplifier panels, however, are provided with test jacks which are connected to resistances in the plate circuits. A reading of the voltage across the resistance gives a measure of the plate current for the associated tube without disturbing the amplifier performance while the amplifier is in service. A portable tube testing set, figure 18, has been designed for this measurement.

Provision is being made for the removal of an amplifier from an active circuit without interruption of service. A spare amplifier at each repeater station can be substituted for the active one by connecting it to jacks at the sealed terminal and operating associated relays to make a quick transfer.

Apparatus is also furnished which permits the substitution of a new link between attended points for one which develops trouble. A complete high-frequency circuit for each direction of transmission will generally be reserved as a spare. It can be substituted for any working high-frequency circuit without interfering with service by paralleling the transmitting ends of the spare and working circuits and patching the receiving ends through relays. The operation of a key controlling these relays substitutes the spare circuit for the working one with a transient disturbance of but one or two milliseconds.

Three pilot frequencies, 15.9, 27.9, and 55.9 kilocycles, which are produced at the transmitting terminals, may be used to check the levels at the main repeater points and the receiving terminals. This is done by means of a special testing circuit which can be bridged across a pair to detect the level of the pilots without interference to service.

A heterodyne oscillator having a frequency range from 60 cycles to 150 kilocycles has been developed for use in testing this and other carrier systems. Its frequency is calibrated at 60 cycles against the power mains and at 100 kilocycles against a quartz crystal. This oscillator is shown in figure 19. A portable test set, developed for measuring transmission gains and losses with high precision, is shown with the cover removed in figure 20.

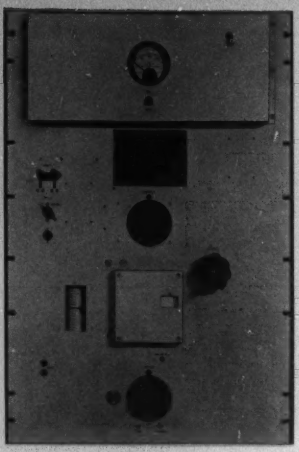

Figure 19. Testing oscillator

Figure 20. Transmission measuring set

Conclusion

The type *K* system makes possible the application of carrier to toll cables of existing type, whether installed underground or aerially. The blocks of 12 circuits each, which it furnishes, seem to be a convenient size for routes where large numbers of circuits are concentrated. It is to be expected, of course, that substantial modifications and improvements will be made in this system through further development effort. In its present form, however, it constitutes an important stage in the history of carrier development. Plans already under way call for the application of large numbers of such systems to meet rapid growth in long-distance traffic.

This new system forms merely one phase of a concerted development effort on broad-band carrier transmission systems.[9,10] There is every indication that, taken collectively, these broad-band systems will have far reaching effects upon the toll telephone plant of the Bell System. A transition is already under way from the time when carrier was used only on open wire, and comprised only a small part of the toll plant, to a time when carrier systems will furnish a major part of the toll circuit mileage of the Bell System. The type *K* system is clearly destined to play an outstanding part in this evolution of the toll plant along carrier lines.

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Discussion

For discussion of this paper see page 259.

Cable Carrier-Telephone Terminals

By R. W. CHESNUT (MEMBER AIEE) L. M. ILGENFRITZ (NONMEMBER AIEE) A. KENNER (ASSOCIATE AIEE)

Synopsis: This paper describes the circuits, performance, and equipment features of the terminals of a new 12-channel carrier system for application to existing toll cables. The 12-channel group of terminal apparatus has been designed also to form a basic part of the terminals of other carrier systems now under development, such as the type-*J* system for open wire and the coaxial system.

Introduction

ABOUT 20 years ago the first commercial carrier telephone system was installed between Baltimore and Pittsburgh. Until recently, telephone circuits were obtained by carrier methods largely on open-wire lines. The notable exceptions were on short deep sea submarine cables.[1,2] Ten years ago, experiments were initiated which now have resulted in the design of a carrier system which can be applied with substantial economy to existing long distance toll cables on land. Its general features are described in another paper.[3] The present paper describes in detail the circuits and performance of the carrier terminals of this system.

General Features

The carrier system for existing cables, designated type *K*, is designed to provide 12 telephone channels in the frequency range between 12 and 60 kilocycles, using one nonloaded 19-gauge paper insulated cable pair in each direction. Previous carrier systems employed for open-wire lines used vacuum tubes for the modulating or translating circuits and electrical filters composed of coil and condenser networks for separating the frequency bands associated with the respective channels. The terminals of the new type-*K* system are simpler and yet provide improved performance by using copper-oxide bridges for the modulation function and quartz-crystal filters[4] for the separation of the individual channel bands.

The quartz-crystal filter is economical only in a comparatively high frequency range, necessitating the use of high intermediate frequencies. The high intermediate frequencies are reduced by a second stage of modulation to the desired range of frequencies for transmission over the line. Copper-oxide bridge circuits again are used for this group-modulation stage. In all cases they are connected to suppress the carrier. To provide the various carriers required for modulation and demodulation, a carrier supply system has been designed somewhat along the lines of an office power-distribution system using bus bars and protective arrangements for the various carriers. Each carrier supply system is capable of supplying as many as ten carrier terminals, or a total of 120 two-way channels.

Because of the large number of circuits involved, every effort has been made to provide reliable operation of the carrier supply and common terminal equipment. The terminal and carrier supply equipment is designed to permit maintenance tests for checking the performance of amplifier tubes and to permit switching between regular and spare equipment without interruption of the large number of circuits involved.

The emphasis placed upon ease of maintenance and the necessity for more careful handling of higher frequency circuits have resulted in new equipment design features. These include new cable terminals, new shielded office cabling, and panels arranged for front wiring and maintenance which are mounted on racks having wiring ducts at both edges of the bays. In the following sections a more detailed description is given of the circuits, their performance, equipment, and maintenance features.

Circuits

The frequency allocation for one direction of transmission and a block schematic of one terminal are shown in figures 1 and 2 which supplement each other and need little explanation. The 12 voice bands shown at the left in figure 1 are modulated individually in the channel modems. (The term "modem" has been coined to mean a panel or equipment unit in which there is both a modulator and a demodulator to take care of both the outgoing and incoming signal.) This forms a 12-channel block lying between 60 and 108 kilocycles which is then modulated in the group modulator by a 120-kilocycle carrier to move the block down in the range from 12 to 60 kilocycles for transmission to the distant terminal. On the receiving side the processes are reversed. One of the channels as well as the group modem of figure 2 is presented in more circuit detail in figure 3. This shows the circuit from the point where the voice comes into the carrier system to the point where the 12 carrier sidebands go out onto the cable and vice versa.

At the left the four-wire terminating circuit serves, not only as a device to transform from a two-wire to a four-wire circuit, but also as a high-pass filter to eliminate, from the input to the carrier system, noises below about 200 cycles, such as telegraph harmonics, 20-cycle ringing, 60-cycle power, etc., which may be present on connected voice-frequency circuits. Otherwise these noise frequencies which are below the voice range would modulate and pass through the terminal to load unnecessarily the carrier repeaters along the line, as well as to interfere with the level indications of the pilot channels.

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1. For all numbered references, see list at end of paper.

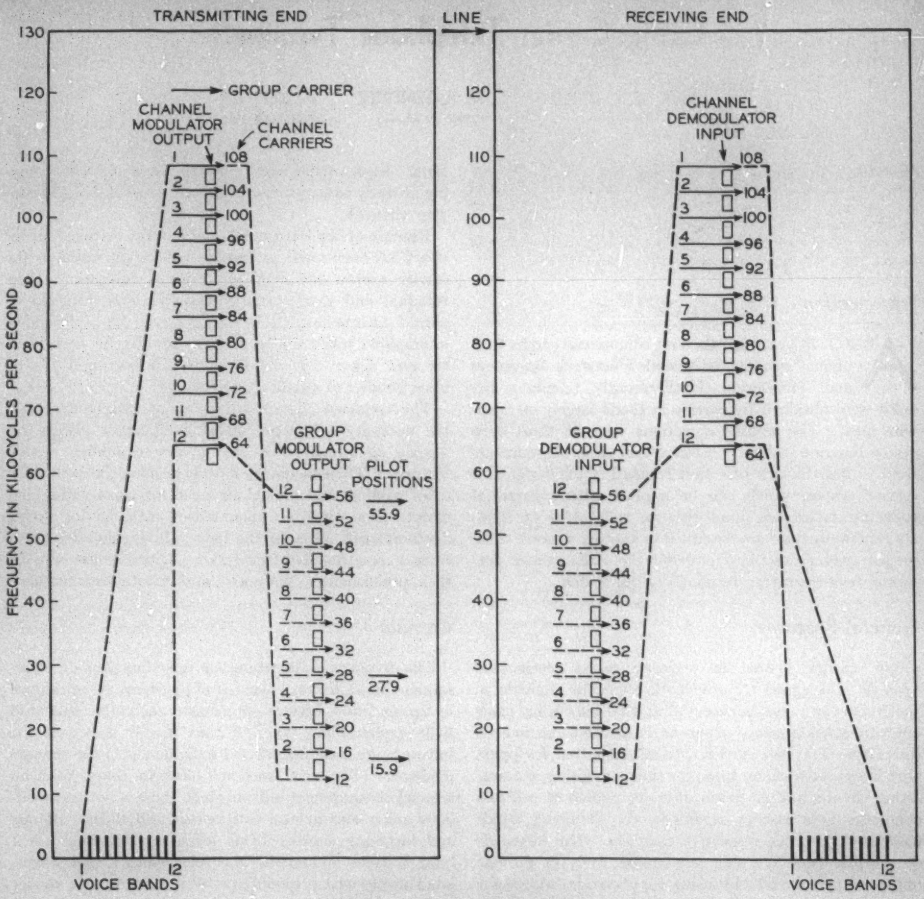

Figure 1. Frequency allocation

From the terminating equipment the circuit loops through jacks which have paralleled contacts for reliability. The level at this point is −13 decibels compared with the transmitting toll switchboard, which level is expected to be generally used in the Bell System for all multichannel carrier-telephone systems. Then comes the channel modulator which consists of four copper-oxide disks, each three-sixteenths of an inch in diameter, potted in a small can. This makes a very simple and inexpensive modulator which is much more satisfactory than tubes. It seems to have an indefinite life (some have been on life tests as modulators for about five years). The carrier power required is about one-half milliwatt to modulate satisfactorily a single telephone circuit level of −13 decibels.

The modulator produces the usual two sidebands and the lower one is selected by the quartz crystal channel filter described in another paper.[4] This sideband, joined by eleven others, is stepped down to about the iterative impedance of the shielded office cabling. In the office cabling the 12 channels pass through the high frequency patching bay to the double balanced group modulator of copper oxide where they are joined by three pilot-channel frequencies.

The group modulator uses the same copper oxide as that in the channel modulator described above, but the carrier power is about 50 times greater (about 25 milliwatts) in order to keep down unwanted modulation produced between the 12 sidebands. To that same end the level of each sideband is made low (−46 decibels), and the double balanced type of circuit is used to balance out some of the undesired products. It also balances out the

12 incoming bands in the range 60 to 108 kilocycles from the output and so simplifies the following group modulator filter.

From a level of −57 decibels the 12 channels, now in the range from 12 to 60 kilocycles, are amplified to +9 decibels for delivery to the 19-gauge pair in the lead covered toll cable. The amplifier is a three-tube negative-feedback type, using pentodes and operating with 154 volts plate battery which is composed of the usual 24-volt filament battery and 130-volt plate battery in series. The last tube is a power tube and does not overload until a single-frequency output of about one watt is reached.

On the receiving side in figure 3, the 12 incoming channels, in the range from 12 to 60 kilocycles, pass from the amplifying and regulating equipment,[3] to the group demodulator. This is identical with the group modulator described above and transfers the 12 channels to the range 60 to 108 kilocycles. The channels are then amplified to a −5 decibel level by an amplifier of the negative-feedback type using two low-power pentodes with 154-volt plate battery as described above for the transmitting amplifier.

From there the 12 channels are separated by the filters which are identical with those on the transmitting side, and are then demodulated and amplified to a +4 decibel level as shown for one channel in figure 3. The demodulator is identical with the modulator but it is poled oppositely on the carrier supply so that the d-c components of modulation in the modulator and demodulator neutralize each other and thereby avoid developing an undesirable voltage bias. The poling also reduces somewhat the amount by which stray frequencies have to be suppressed in the carrier supply. The demodulator amplifier has a slide-wire gain-control rheostat to equalize channel levels which functions by changing both the grid bias on the tube and the amount of negative feedback which is introduced by the rheostat. The sliding contact in the slide wire is made practically free from contact trouble by the space current of the tube flowing through it. As the rheostats are only about 1,000 ohms and small in size, they can easily be mounted at a distance from the amplifier in the voice-frequency jack field.

The carrier supply for the 12 channels from 64 to 108 kilocycles, and for the group modems of 120 kilocycles, is derived in the circuit shown in figure 4. A regular generator is shown at the top in solid lines and an emergency generator at the bottom is shown in dotted lines. Between the two is an automatic transfer circuit (in dotted lines) which transfers to the emergency whenever the regular generator fails to supply the proper amount of 120 kilocycles to the 120-kilocycle bus.

At the upper left-hand corner is shown a four-kilocycle tuning fork, of an alloy having a low temperature coefficient driven by the tube to its right to operate as an oscillator of very stable frequency. The next, or control tube, amplifies the four kilocycles to drive the push-pull power stage where a power of about four watts is developed. This passes through the four-kilocycle filter to the nonlinear coil where odd harmonics of four kilocycles are produced. The underlying principles of operation of this coil have been published.[5] To derive even harmonics of four kilocycles, the copper-oxide bridge is used which rectifies about half the energy of the complex wave of odd harmonics but, by balance, greatly reduces the amount of the odd harmonics present in its output. Odd harmonics are obtained at one point and even at the other. This separation into odd and even harmonics by the balance of the copper-oxide bridge provides effective loss of about 30 to 40 decibels and reduces the requirements on the carrier-supply filters which follow.

The two branches pass through hybrid coils to the banks of channel-carrier supply filters. These separate the frequencies and feed them to 12 carrier-supply bus bars, one for each channel frequency. From these the individual modems are fed through protective resistances so that an accidental short circuit on one of the modems will not cut off the carrier supply to the others.

The hybrid coils permit the two generators to be connected so that either can feed into the same bank of chan-

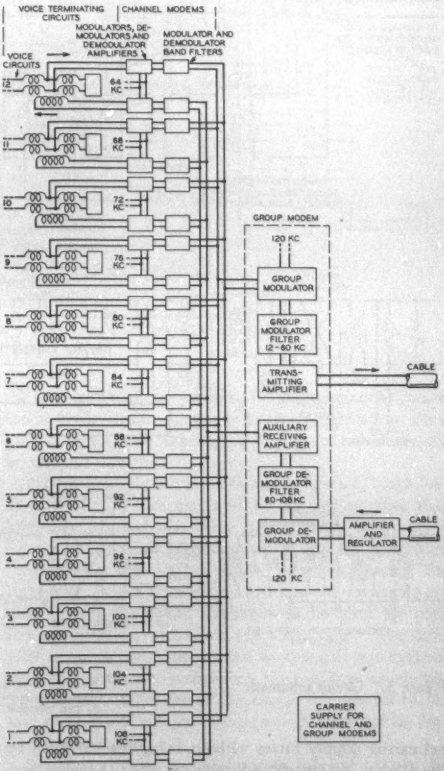

Figure 2. Block schematic

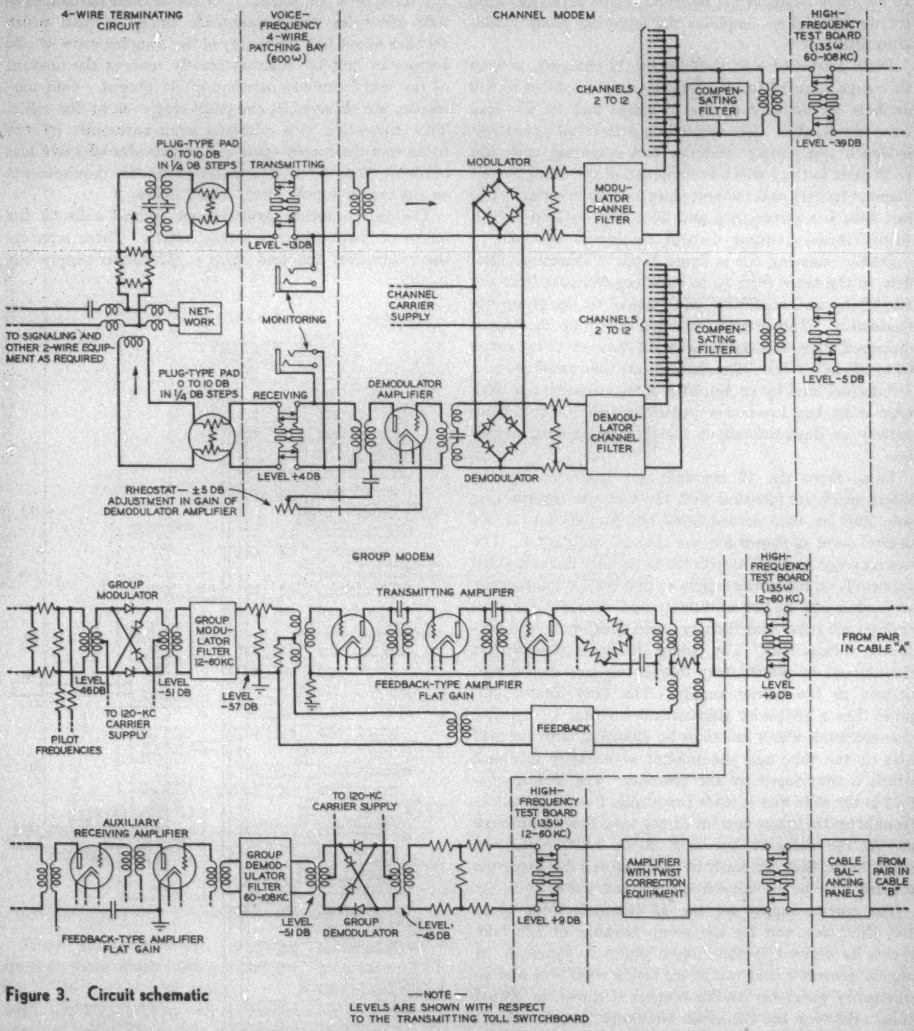

Figure 3. Circuit schematic

nel carrier supply filters without being reacted upon by the other. No switching is required when changing from regular to emergency supply.

The 120-kilocycle carrier which feeds the group modulators of ten systems or a total of 120 talking channels must be very dependable. Therefore separate filters are used for the regular and emergency supply and separate amplifiers for the large power required by group modulators. Regular and emergency distributing busses are provided. Each group modulator and each group demodulator is wired through protective resistances to the regular bus and through another set of protective resistances to the emergency bus. With this arrangement an accidental short circuit even across one of the busses or across one of the output coils of one of the 120-kilocycle amplifiers will not stop the whole supply of 120 kilocycles.

The four-kilocycle oscillator of the emergency generator is in constant operation so that when it is needed no time is required to start it, but the grid bias on the second tube is held above its cutoff value by the automatic transfer circuit. This prevents the four kilocycles from going further until called for in an emergency.

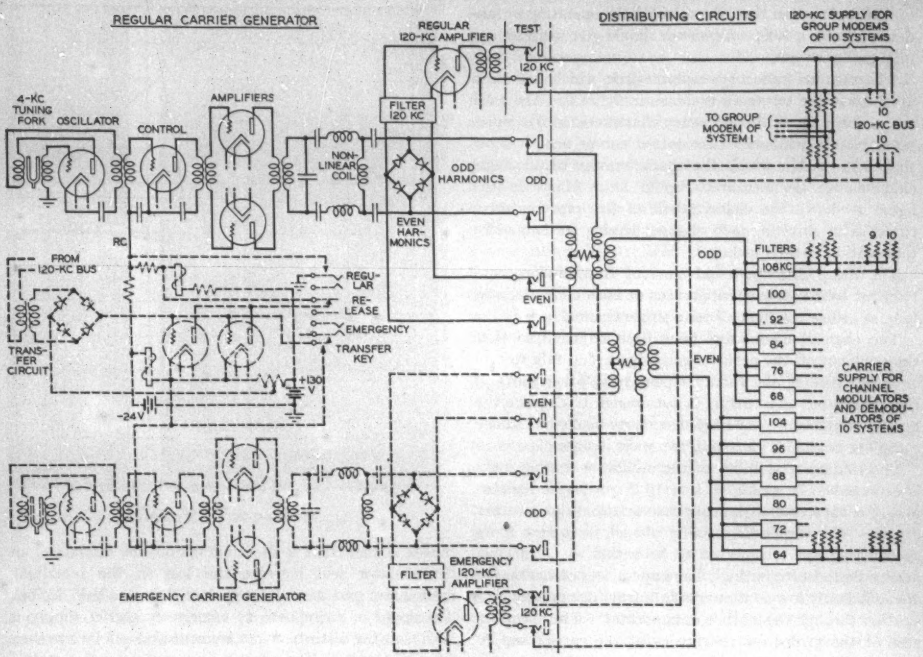

Figure 4. Carrier-supply circuit

An emergency is indicated when there is no 120-kilocycle supply on either the regular or emergency bus. When this happens, the copper-oxide rectifier in the transfer circuit gets no 120 kilocycles and so loses its rectified voltage. This triggers off one or both of the two gas-filled tubes (multipled for safety) which increases the grid bias on the control tube of the regular generator to stop its four-kilocycle supply and at the same instant restores the bias to normal on the control tube of the emergency to let its four kilocycles pass through and put the whole emergency circuit into operation. The keys in the transfer circuit are provided for maintenance purposes and to return from emergency to regular operation, since the gas tube circuit is arranged to transfer automatically in only one direction.

The pilot supply circuit is shown in figure 5. The 3.9-kilocycle tuning-fork oscillator at the left supplies that frequency, through the three transformers, to the three copper-oxide modulators whose carriers are obtained from the regular channel-carrier supply busses as shown. The three filters, which are identical with channel-carrier supply filters, select the lower sidebands to be used for pilot frequencies at 64.1, 92.1, and 104.1 kilocycles. The three pilot frequencies are distributed to the different systems through protective resistances from a bus as shown. They are set 100 cycles off the carrier frequencies to obtain locations of minimum interference from carrier leak and other sources.

Signaling circuits do not form an integral part of the carrier terminal equipment. Signaling equipment of a type already widely used in the Bell System for toll circuits, is connected between the toll switchboard and the four-wire terminating set of the individual channel.

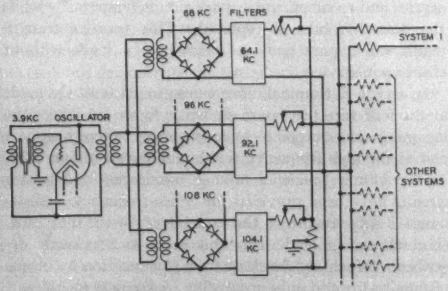

Figure 5. Pilot supply circuit

Transmission Performance

In general, the performance requirements set down as objectives in the development of this system were based

on the assumption that five carrier links operating in tandem and over a 4,000-mile circuit should give satisfactory, high-grade service.

The channel-frequency characteristic which has been attained in the terminals is shown in figure 6. The solid curve below shows the frequency characteristic of a representative channel, while the dotted curves near it show the limits within which the characteristics of all single channels, so far measured, would fall. Above in the figure is shown the characteristic of five representative channels in tandem, each channel having its two voice terminating circuits included.

The delay distortion and time of transmission, contributed by all terminal apparatus at both ends of a system, are shown in figure 7 for a single channel.

The channel modulators have been adjusted so that they will cut off the peaks of excessively loud talk to prevent overloading the carrier repeaters or other parts of the circuit, but this cutting is not enough to degrade the quality of speech. The single frequency load curve of one complete channel is plotted in two ways in figure 8.

The frequency stability of the oscillating tuning forks is expected to be within $\pm 1 \times 10^{-6}$ per degree Fahrenheit on all systems, with negligible variations due to other causes. The amplitude stability of each frequency at its distributing bus is expected to be within $\pm \frac{1}{4}$ decibel over a period of months. The impedances of the busses are sufficiently low so that crosstalk from one system into another through this path is unimportant. The effectiveness of the protective resistances at the carrier supply busses is such that a short circuit on one modulator or demodulator will increase the loss in the remaining modulators and demodulators less than one-half decibel. The speed of switchover to emergency carrier supply is such that the disturbance to transmission will be less than 10 milliseconds. The effect on speech is not detectable.

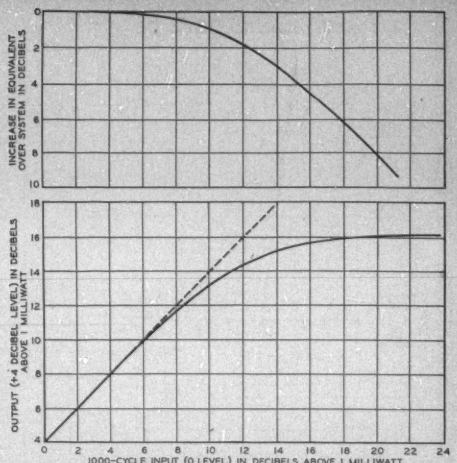
INCREASE IN EQUIVALENT OVER SYSTEM IN DECIBELS
OUTPUT (+4 DECIBEL LEVEL) IN DECIBELS ABOVE 1 MILLIWATT
1000-CYCLE INPUT (0 LEVEL) IN DECIBELS ABOVE 1 MILLIWATT

Figure 8. Channel load curve at 1,000 cycles

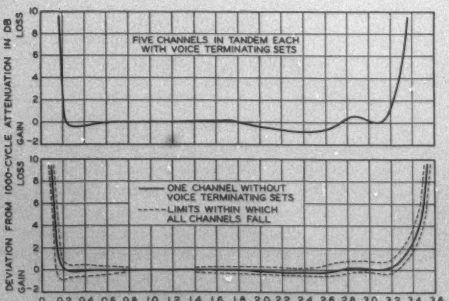
DEVIATION FROM 1000-CYCLE ATTENUATION IN DB LOSS GAIN
FIVE CHANNELS IN TANDEM EACH WITH VOICE TERMINATING SETS
ONE CHANNEL WITHOUT VOICE TERMINATING SETS
LIMITS WITHIN WHICH ALL CHANNELS FALL
FREQUENCY IN KILOCYCLES PER SECOND

Figure 6. Channel frequency characteristic

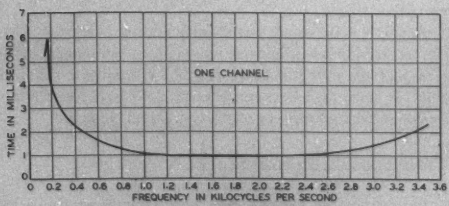

Figure 7. Delay characteristic

Maintenance Features

Since the type-*K* system provides more circuits in a group than ever before, it is essential that appropriately better maintenance facilities be furnished. Wherever vacuum tubes are used, jacks have been included to permit testing the condition of the tube by plugging in a new type of test set. The testing of a working tube with this set will not produce an appreciable reaction on performance of the circuits involved. When it has been determined that a tube in the common equipment is nearing the end of its useful life, a special transfer cord circuit is used to remove the circuit involving the tube from service and to substitute a spare circuit temporarily while the defective tube is replaced. This transfer from a regular to a spare and vice versa can be made without effect upon service.

In a type-*K* terminal office transmission tests are made at the four-wire test board shown in figure 9*A* where the incoming and outgoing voice-frequency circuits appear and at the high frequency test board shown in figure 9*B*. At the former, four-wire talking, monitoring and testing circuits have been provided for voice-frequency maintenance. Adjustment of the equivalents of the individual channels can be made from this point as previously described. Much can be done from this position by means of monitoring and noise measuring to diagnose troubles.

At the high-frequency testboard the circuits are brought

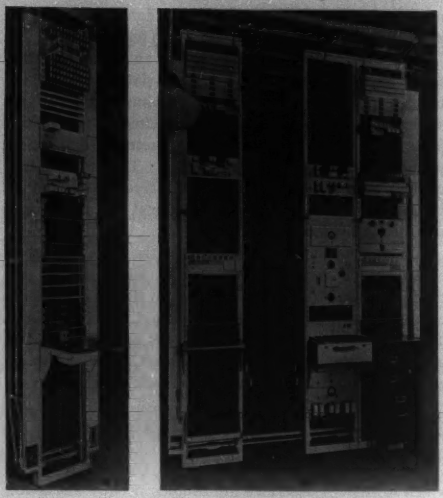

Figure 9. Test positions

A—Voice frequency *B*—High frequency

through jacks and high-frequency measuring apparatus is provided. Measurements can be made on operating systems to determine the performance of the intermediate repeaters and regulators with respect to level and equalization over the frequency range from 12 to 60 kilocycles. Loss and gain measurements also can be made either between this point and the voice-frequency four-wire test board, through the carrier terminal equipment or through the next adjacent repeater or terminal office at high frequencies. It is possible to test the high-frequency portion of the terminal and to substitute a spare, by patching or rapid transfer, for a defective or potentially defective group modulator, transmitting amplifier, group demodulator or receiving amplifier.

Some of the high-frequency testing equipment is shown mounted on the middle bay of figure 9*B*, of which one of the most important units is the 1- to 150-kilocycle test oscillator located at the center of this bay. It is a heterodyne type of oscillator which covers the frequency range with a continuous film strip scale about 300 inches long. Its maximum output is about one watt and this varies less than one decibel over the entire range. It is provided with built-in calibrating features and can be set to any frequency with an absolute accuracy of about 25 cycles. It is used as the tuning control of the pilot level measuring circuit. An auxiliary scale on the oscillator permits tuning the measuring circuit directly in terms of frequency.

The pilot-level measuring circuit is of the double heterodyne type and includes a copper-oxide modulator which is supplied with carrier from the heterodyne oscillator, an intermediate frequency 130-kilocycle crystal filter of 10 cycles band width, a high frequency amplifier for this frequency, a copper-oxide demodulator supplied with carrier from a 129-kilocycle fixed frequency oscillator, a voice-frequency amplifier, and calibrating circuit. The input impedance of the measuring circuit is high so that when it is bridged across a line pair at the high-frequency test-board jack fields it does not produce appreciable loss to the line. The circuit permits measuring each of the three pilot frequencies to check levels and equalization of operating systems. The panels comprising the circuit are shown below the oscillator in figure 9*B*.

Mounted on a shelf just below the oscillator is the transmission-measuring set which contains a highly accurate thermocouple and meter-combination with calibrating circuits, wide-range repeating coils, a test-key circuit, and attenuators, one of which can be set in steps of one decibel up to a total of 90 decibels.

Equipment Features

Because of the large number of systems likely to be terminated in an office, the jacks are concentrated in a group of bays located together for ease in patching and testing. There are in general five major divisions of the terminal equipment consisting of channel-modem bays, group-modem bays, carrier-supply bays, high-frequency test board, and four-wire voice-frequency patching board and associated voice terminating equipment. The general arrangement in an office is such as to simplify the cabling between various groups of equipment.

The cabling of a high-frequency jack bay, shown in fig-

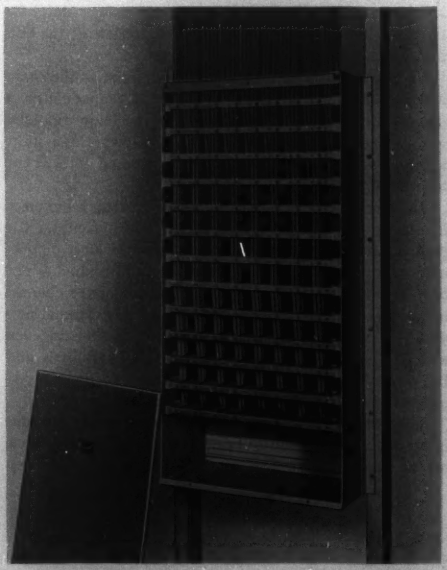

Figure 10. Cabling of high-frequency jack bay

Figure 11. Carrier-equipment bays

A—Channel *B*—Group
C—Carrier and pilot supply

ure 10, illustrates the congested wiring condition occurring when a large number of heavy shielded wires is run to one location. Because of this congestion the jacks in this bay are mounted or removed from the front.

The concentration of equipment in the modem unit is made possible by the small size of the copper-oxide bridges and the filters. Figure 11*A* shows 12 modem units for two systems on adjacent bays with space left at the bottom for the six modems of a third system.

The group modems are about the same size as the channel modems and include a modulator, a demodulator, a transmitting amplifier, and auxiliary receiving amplifier with associated filters. Figure 11*B* shows three units for three systems with space for six additional units at the bottom of the bay.

The carrier supply equipment for ten systems is mounted in one bay as shown in figure 11*C*, which includes the regular and emergency generators, transfer unit distributing equipment and pilot channel supply panel. The bays of this type are located near their associated channel equipment because the supply is chiefly for channel modems. One carrier distributing unit provides for the even and another for the odd harmonics. All terminals and bus bars of these units which are common to the ten systems are protected by insulating covers.

The four-wire voice-frequency jacks for all the systems in an office will ordinarily be grouped in associated bays, one of which is shown on figure 9*A*. A bay will accommodate five systems as an average, that is, 60 voice circuits including the necessary pads and telephone set.

The high-frequency test board is an arrangement of sealed test terminals, high-frequency patching jacks and high-frequency testing equipment mounted on bays as shown in figure 9*B*. Only a few high-frequency patching jacks were required initially and these were therefore mounted above the sealed terminals. This arrangement of bays with the addition of a high-frequency patching bay at the right of each sealed terminal bay will accommodate 100 systems.

The carrier pairs are split off from the main toll cables at splices in the cable vault. The input circuits are carried thence in lead covered cable to the cable crosstalk balancing bays and thence to the input sealed terminal. The output pairs run directly from the output sealed test terminal to the splice in the cable vault. The remaining high frequency wiring from rack to rack is shielded wire.

Conclusion

The carrier-telephone terminals for the type-*K* system which have been described are simpler, occupy less space, and provide better transmission performance than multichannel carrier terminals used previously in the Bell System. As part of a general development of broad-band transmission systems, it is very desirable to employ equipment which can be used in common with several systems. The 12-channel bay, much of the carrier supply, and all of the voice-frequency terminating equipment of this type-*K* system terminal will be used to form corresponding parts of the terminals for the 12-channel open-wire system and the coaxial system, both of which are under development. This not only has simplified the development work, but also will result in greater mass production of these common parts and provide desired uniformity of voice-frequency terminating levels and maintenance arrangements.

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3. Carrier Telephone Systems for Toll Cables, C. W. Green and E. I. Green. Presented at the 1938 winter convention of the AIEE.

4. Crystal Channel Filters for the Cable Carrier System. C. E. Lane. Presented at the 1938 winter convention of the AIEE.

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Discussion

For discussion of this paper see page 259.

Crystal Channel Filters for the Cable Carrier System

By C. E. LANE
ASSOCIATE AIEE

SINCE the channel selecting filters used at the terminals of the 12-channel cable carrier system are the principal filters in the system this paper is concerned primarily with these filters. Their importance is evident from the fact that they represent over one-third of the cost of the system terminals.

Many new features appear in these channel filters. The most outstanding is the use as filter elements, along with inductance coils and condensers, of plates cut from crystalline quartz. It is for this reason they are called "crystal filters." In addition, however, the inductance coils, some of the condensers, and also the filter assemblies have in them new features. Only after a number of years of laboratory experimentation with filters using crystal elements, studying their advantages and limitations, was the cable carrier system planned to use such filters.

There are 12 channel filters which transmit the lower side bands derived from the modulation of the speech signals with carrier frequencies spaced four kilocycles apart from 64 to 108 kilocycles. An insertion loss frequency characteristic which applies for each of the 12 filters is shown in figure 1. Regarding a ten decibel loss increase as the cutoff as compared with transmission at 1,000 cycles, the voice-frequency band for a single carrier link, largely determined by the characteristics of the channel filters, extends from approximately 150 to 3,600 cycles. For five links the band extends from about 200 to 3,300 cycles. This is a 600 or 700 cycles wider frequency band than the present three-channel open-wire carrier system. The maximum delay distortion in the transmission band of each of the filters is about 0.4 millisecond. As many as ten of these filters may appear in tandem in the longest talking circuits. The total delay distortion in such cases would then not exceed 4 milliseconds. This is not objectionable since the average listener cannot observe the effect of delay distortion unless it exceeds about 10 milliseconds. A representative filter schematic is shown in figure 2. The condenser shown by the dotted line at the left is used only in the two lowest frequency filters to obtain an impedance transformation internal to the filters and thereby permit the use of crystals of practical thicknesses for these filters. However, the equivalent circuit for each of the 12 filters is the same. In the system the filters work in parallel at one end and between terminating impedances of 600 ohms. The two condensers appearing in the series arms at the left end of the filter schematic are used in obtaining satisfactory operation of the filters in parallel and otherwise might be omitted provided the inductance at this end was made smaller at the same time.

Figure 2 indicates the separate physical elements and the manner in which these are connected in the filters. In considering the performance of the filters the crystal elements are replaced by their equivalents, an inductance and capacitance in series, shunted by a second capacitance as shown in figure 3. Also, the condensers in shunt across the filter are shown inside the lattice combined with the direct capacitance of the crystals and the inductances are relocated in series in each lattice arm. In making this conversion, however, the effective resistance of the in-

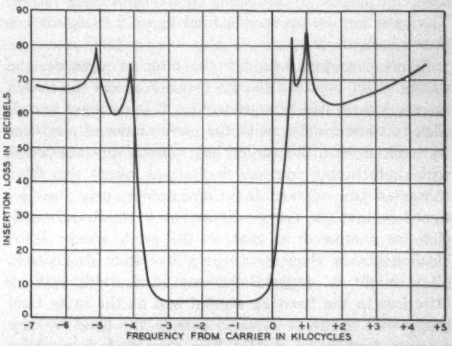

Figure 1. When plotted in cycles removed from the carrier frequency, the insertion loss frequency characteristics of each of the 12 crystal channel filters are for all practical purposes identical

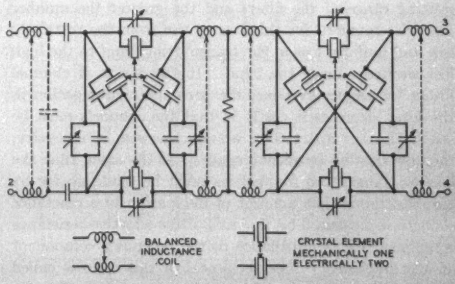

Figure 2. The schematic circuits of each of the 12 filters are the same except for the addition of the condenser shown by the dotted lines which appear only in the two lowest-frequency filters

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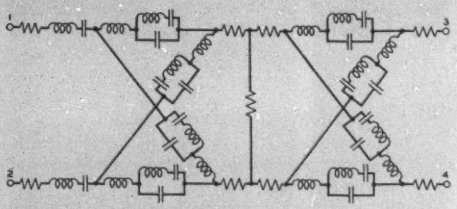

Figure 3. The schematic circuits of the filters are each equivalent to two lattice sections with a resistance pad between them, resistances at each end, and at the paralleling end a coil and condenser which resonate at the midband frequency

ductance coils are, for reasons which will appear later, shown remaining outside the lattice. Also the capacitances and the portion of the inductance which are used solely for purpose of paralleling are left outside the lattice. The basis for the conversion from figure 2 to figure 3 is shown in figure 4.

Before considering further the filter as a whole, the nature of the crystal elements themselves and the reason for using them will be considered. It is common knowledge to those familiar with the performance of electrical wave filters that the energy loss unavoidably associated with inductances imposes limitations upon the filter characteristics obtainable. Capacitances may be designed so that the energy dissipation is small and negligible as compared to that in the inductances. With ideal reactance elements entirely free from dissipation, filters might be designed for any band width with as little loss in the band as wanted and at the same time frequencies might be rejected outside the band by any amount desired, no matter how near such frequencies were to the edges of the transmitting band. Of course the sharper the filter cutoffs, other requirements being the same, the more complex the filter structure would be even neglecting dissipation. The greater the dissipation in the filter elements, the greater the loss in the transmitting range of the filters and the greater the number of cycles required for this loss to rise from the relatively low and uniform loss in the transmitting band to the high loss wanted outside the band. In the design of channel filters for carrier systems, the presence of dissipation in the filter elements is costly in that the channels must be spaced farther apart than would otherwise be necessary, thereby wasting frequency space. At the same time the loss to transmitted frequencies must be made up for by amplification. The amount of dissipation in a reactance element is measured by the ratio of the effective resistance component of its impedance to the reactance component at any frequency. The reciprocal of this ratio is called the Q of the reactance and hence is a measure of efficiency or freedom from dissipation. In the design of inductances in the form of wire-wound coils, it is generally not practical to obtain Q's much in excess of 200 or 300 at any frequency. The quartz crystal element used in the filters as previously stated is equivalent electrically to a two-terminal reactance consisting of an inductance and capacitance in series shunted by a second capacitance. For the Q of the inductance in the equivalent circuit of the crystal element a value of 15,000 or more can readily be obtained. It is for the purpose of utilizing this high Q inductance and obtaining the benefits therefrom that crystal elements are used in these filters.

The filter schematic in figure 2 shows crystal elements in each filter section; the two in the lattice arms and the two in the series arms in each case are identical. Electrically there are four crystals in each section but for reasons of economy and for convenience in handling and adjusting the crystals those in corresponding arms are physically one. This is possible since the filter is a balanced structure and the two like crystals vibrate in unison. Figure 5 is a photograph which shows a representative double crystal element taken from each of the 12 filters. The four crystals in the lowest-frequency

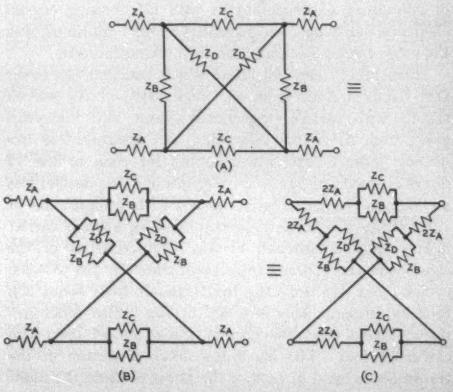

Figure 4. It does not alter the transmission properties of a network such as shown in figure 4A to remove the impedances in shunt and outside the lattice and replace them by impedances of equal magnitude in shunt across each lattice arm nor by removing the impedances in series with the lattice and replacing them by series impedances inside the lattice of twice the magnitude of those removed

filter range from 40.2 millimeters to 41.8 millimeters in length and those in the highest-frequency filter from 23.8 to 24.3 millimeters. The thickness of the crystals in all four of the lowest-frequency filters are 0.63 millimeters, in the next four filters 0.82 millimeters, and in the highest-frequency filters 1.1 millimeters. Uniformity in thickness is maintained as far as practicable since it contributes to economy in manufacture of the crystal. Within the range using the same crystal thickness the impedance and frequency differences, called for by the design of the different filters, can be provided by variations in width and length of the crystals. The ratio of width of the crystals to their length ranges from about $^1/_2$ to $^4/_5$.

The major surfaces of the crystals are plated with a thin layer of aluminum deposited by an evaporation process. This plating is divided along the center line lengthwise of the crystals to form the two electrically independent crystals. Since the crystals vibrate longitudinally with a node across the middle, they are clamped at this node in mounting. Figure 6 shows the orientation of the crystal plates with respect to the natural axes of the quartz from which they are cut. The plates are cut as

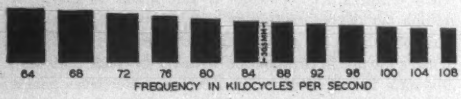

Figure 5. The length of the crystal elements used in the different filters varies about inversely as the frequency of the filter band location

accurately as practical to the dimensions computed making a small allowance in length and then the crystal is finally adjusted in an electrical circuit by grinding the end of the crystal until the resonant frequency falls within five or ten cycles of that desired.

Considering again the filter schematic as a whole, figure 3, and neglecting the dissipation in the crystals

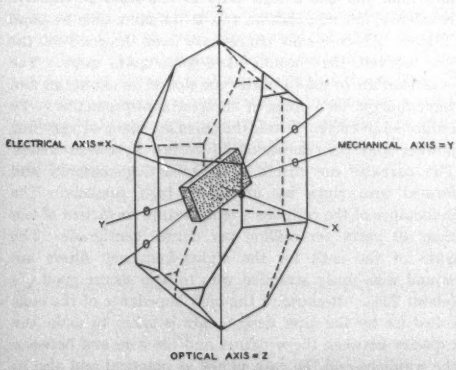

Figure 6. The crystal elements are cut with their major surfaces perpendicular to the electrical axis of the natural quartz, with their side surfaces making a small angle with the mechanical axis, and with their end surfaces making a small angle with the optical axis

and condensers, the filter may be regarded as made of two lattice filter sections having ideal reactance elements, that is, elements free from dissipation. The location of the effective resistance of the coils outside the lattice, for purpose of performance analysis, shows, how, at the end of the filter these resistances may be regarded as part of the terminating impedance between which the filter works and how between the filter sections the resistances may be combined with a shunt resistance to form a resistance pad which matches the image impedance of the two filter sections. The effect, then, of the coil resistances is primarily to provide a flat loss over the entire frequency range and does not affect appreciably the shape of the loss characteristic furnished by the reactance inside the lattice sections.

In considering the performance of lattice-type filter sections, it is common practice to sketch together the frequency reactance curve of the two lattice arms Z_x and Z_y. This is done for one of the filter sections and is shown in figure 7. In the frequency range where the two curves are of opposite sign the filter transmits and where they are of the same sign there is attenuation. At the point where the two curves intersect there are attenuation peaks of very high loss. The reactance curves of figure 7 are for the filter section accountable for the pair of attenuation peaks shown in the filter characteristic which are the closer to the edges of the transmitted band. For the other section the cross-over points of the two reactance curves are farther away from the band, since this section is responsible for the outer pair of attenuation peaks. The design of the filters consisted in determining values for the inductance coils, condensers, and crystals, such that the reactance curves of the lattice arms of the filter passed through infinity and intersect with each other at the desired frequencies and, at the same time, of determining the impedance level for all of the elements such that the filters would have the right image impedances.

The curves of figure 7 would seem to indicate a somewhat greater band width for these filters than shown by the insertion loss characteristic of figure 1. The reason

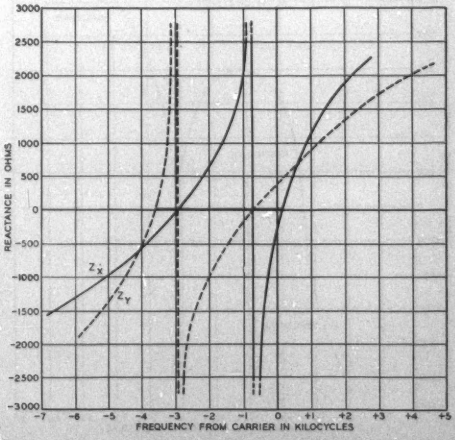

Figure 7. In a lattice filter section transmission occurs for frequencies where the impedances for the two arms of the lattice are of opposite sign and attenuation peaks of very high loss occur where the impedances cross

for this can best be explained by referring to the image impedance of one of the filter sections as shown in figure 8. Within the band the image impedance is, of course, a pure resistance which varies with frequency. It is about 800 ohms at midband frequency and falls rapidly to zero near the edges of the band. Assuming the effective resistance of the coils which is about 100 ohms as belonging to the terminating impedances, the filter sections actually work between impedances of about 700 ohms. This means that large reflection losses occur at each end of each filter section near the edges of the transmission band where the image impedance of the filter is very small. It is these reflection losses that are responsible for the actual transmission band being much narrower than it would be with the filter sections terminated in their actual image impedances. The filter sections are designed with 800 ohms image impedance at midband frequency instead of 700 ohms to make the band flatter and somewhat wider than it would be otherwise.

When a number of band filters are operated in parallel it is generally necessary to connect across the paralleled end a two terminal network to correct for the distortion that would otherwise be present in the highest- and lowest-frequency filters in the group. A circuit of the network used for this purpose with the channel filters is shown in figure 9.

The filters employ crystal elements in order to obtain abrupt discrimination between wanted and unwanted frequencies and at the same time to secure low and uniform loss in their transmitting bands. This characteristic must not only be obtained at the time the filters are assembled and adjusted but must be maintained throughout the service life of the filters and not appreciably affected by temperature variations. This imposes severe stability requirements upon the elements used in the filters. The crystal elements themselves are very stable when properly designed and once adjusted will retain at a given temperature their frequencies of resonance within one or two cycles seemingly indefinitely. Their temperature coefficient is only about 25 parts per million per degree centigrade which is not objectionable. The obtaining of suitable inductance coils and condensers for use in conjunction with the crystals that were adequate in stability required considerable development effort. The inductance coils were required to have not only a high degree of stability with respect to temperature

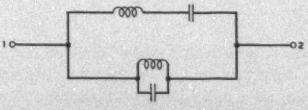

Figure 9. A two-terminal reactance network is connected in shunt across the filters at their paralleling end to improve the characteristic of the highest- and lowest-frequency filters

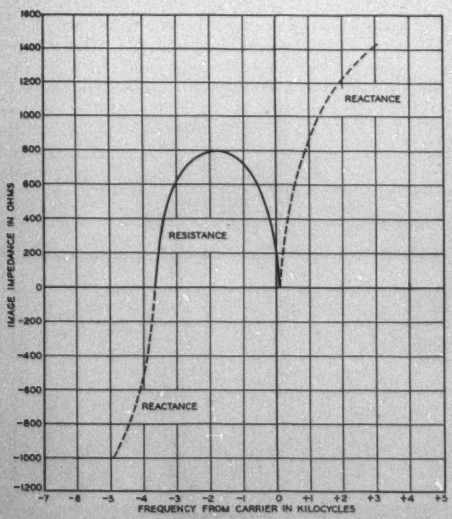

Figure 8. The large reflection losses occurring within the transmission band of the filters and near the edges of this band has the effect of narrowing the width of the transmission band

and time but also a high ratio of reactance to effective resistance, low modulation, and at the same time be small in size. Air-core coils might have been designed for the purpose but they would have been quite large. The coils used are of the toroidal type wound on about one and three-fourths inch rings of molybdenum-permalloy. To reduce eddy-current losses the cores are made of very fine powder and then annealed to reduce hysteresis losses. The particles are mixed with insulating material and formed into rings by extremely high pressure. The inductance of the coils has a temperature coefficient of less than 40 parts per million per degree centigrade. The cores of the coils for the higher-frequency filters are wound with finely stranded wire to help secure good Q's (about 225). Because of the high impedance of the coils called for by the filter design, care is taken to make the capacity between the windings and the core and between the windings and the case as low as practical and also to make stable all such small capacities as must be present.

The two extra condensers used at one end of each filter for paralleling purposes are of a high-grade mica type. The other condensers are all quite special. The fixed ones, ranging in magnitude from about seven micromicrofarads to 100 micromicrofarads are made by plating short lengths of high-grade glass tubing inside and outside with silver. Because of the intimate association of electrodes with the surfaces of the tubes and the low expansion coefficient of the glass used a condenser is obtained that has a temperature coefficient comparable with that of the coils and crystals. No aging effect has been observed. It will be noticed that four small ad-

justable air condensers appear in each filter section. These are used to secure precise initial adjustment of the filter capacitances.

To protect the filter elements against moisture, the filters are hermetically sealed in a container made from a rectangular section of seamless brass tubing with closely fitting plates soldered in each end. One end plate carries four metal-glass seal terminals and a nozzle through which dry air is blown after the filter is assembled. The other end plate is provided with a small hole for the escape of the drying air. After the drying operation the hole in the nozzle and the hole in the opposite end of the filter are closed by soldering. The elements that make up the filter are assembled on a chassis which is completely wired and then slid into the container in assembly. Figure 10 is a photograph showing this chassis and the arrangement of the elements. The elements are located in such a way as to use very short wiring connections which reduce the magnitude of any stray admittances. The wired filter chassis is carefully adjusted by setting the values of the air condenser such that for each filter section the resonance frequencies looking into each end of each section occur where they theoretically should. This compensates for the effect of small capacitances between the filter parts. In the design of the filter parts care is taken to use no material which absorbs moisture readily since such moisture would later be released and raise the relative humidity of the air inside the filter.

If voltages much in excess of about 20 volts are applied across crystal elements at frequencies near resonance, the crystals will break from the mechanical strain of their vibration. The maximum safe voltage across the channel filters at the resonant frequencies of the crystals in them is considerably greater since at resonance the full voltage does not appear across the crystals. In their normal use in the system the voltages across the filters will be very much less than 20 volts.

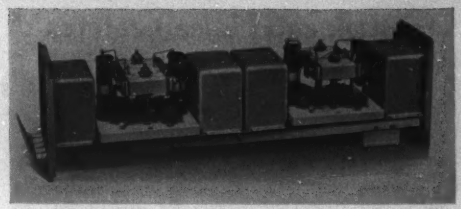

Figure 10. The filter parts are assembled and wired on a chassis which is slid as a unit inside the filter container

Other filters forming part of the terminal apparatus are the group modulator and group demodulator low-pass filters, the channel and group carrier supply filters, and the pilot supply filters. The group modulator and demodulator filters are of the low-pass type employing only coils and condensers as elements. The group carrier supply filter is the same in schematic and mechanical design as the crystal channel filters described. The pilot supply filters and the channel carrier supply filters are equivalent in schematic to one section of the channel filters. Mechanically, of course, they are only about half the size and are hermetically sealed in the same manner.

References

For a further discussion of crystal filters the reader is referred to THE EVOLUTION OF THE CRYSTAL WAVE FILTER, O. E. Buckley, *Journal of Applied Physics*, October 1936, and ELECTRICAL WAVE FILTERS EMPLOYING QUARTZ CRYSTALS AS ELEMENTS, W. P. Mason, *Bell System Technical Journal*, July 1934.

Discussion

For discussion of this paper see page 259.

Crosstalk and Noise Features of Cable Carrier-Telephone System

By M. A. WEAVER NONMEMBER AIEE R. S. TUCKER ASSOCIATE AIEE P. S. DARNELL NONMEMBER AIEE

CROSSTALK and noise are important factors in cable carrier transmission as outlined in the paper "A Carrier Telephone System for Toll Cables" by Messrs. C. W. Green and E. I. Green. Crosstalk and noise limit the number of carrier channels which can be utilized in any one cable, not only by limiting the number of channels which can be placed on a single pair, but by limiting the number of pairs which can be used. Noise also controls the transmission loss which can be permitted between repeaters. Without the crosstalk and noise reduction measures described in this paper, the number of carrier channels per cable would be so few and the spacing between repeaters so short, that the type-*K* carrier system would be impracticable.

Crosstalk

To utilize existing toll cables in the Bell System for frequencies up to 60 kilocycles required the solution of many new crosstalk problems because: (1) crosstalk increases rapidly with the frequency; (2) nonloaded carrier pairs due to their high speed of propagation are especially suitable for very long distances and hence the crosstalk requirements per unit length are relatively severe; (3) the large gains of the carrier repeaters amplify certain crosstalk currents much more than in the case of voice frequency circuits.

Two general effects need to be considered: intelligible crosstalk must be prevented; and a large number of circuits crosstalking into a particular circuit must not contribute an undue amount of noise. The second effect is called babble, since it consists of a multiplicity of unrelated voice sounds which, in the aggregate, are unintelligible.

An important feature is the use of different cables for opposite directions of transmission. This makes the major crosstalk problem the reduction of crosstalk between pairs in the same cable used for transmission in the same direction. The crosstalk currents due to transmission at one end of a disturbing circuit through the distributed couplings with a disturbed circuit tend to arrive at the distant end at the same time since the currents via any of the couplings travel substantially the same distance. This makes it possible to greatly reduce the total effect of these distributed couplings by the use of small adjustable mutual inductance coils connected between pairs at one point in each repeater section.

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1. For all numbered references, see list at end of paper.

If nothing more were done, there would still be objectionable crosstalk since currents from the outputs of carrier repeaters could crosstalk into voice-frequency circuits and these circuits could then again crosstalk into other carrier-frequency circuits at points near their repeater inputs. This effect is minimized by transposing the carrier pairs from one cable to the other at carrier repeater points.

At common voice-frequency and carrier-frequency repeater points there would be an unsatisfactory crosstalk path from a carrier repeater output into all the wires not used for carrier frequencies and from them through coupling between office wiring into similar wires in the other cable and finally into carrier repeater inputs in the second cable. This crosstalk is minimized by the use of carrier-frequency suppression coils in the voice-frequency circuits. These coils also serve the purpose of preventing carrier frequency noise originating in voice frequency circuits from being transmitted into the cables and inducing noise at points near carrier repeater inputs.

Near-End Crosstalk

Near-end crosstalk is the result of coupling between circuits transmitting in opposite directions, while far-end crosstalk is the result of coupling between circuits transmitting in the same direction. Near-end crosstalk coupling between different carrier circuits of the same frequency must be kept very small, particularly near a repeater point, since crosstalk from the output of a repeater into an opposite directional pair near the input of its repeater will be greatly amplified by this repeater.

Crosstalk between carrier circuits within the offices is kept low by careful shielding, segregation, suppression of spurious paths through battery supply, common grounding arrangements, etc.

Since the type-*K* system operates on a "four wire" basis, different electrical paths are used for opposite directions of transmission. Satisfactory near-end coupling in the outside plant is obtained, therefore by placing east bound pairs in one cable and west bound pairs in another. When two cables have relatively heavy sheaths as in the larger Bell System cables, their coupling is sufficiently small even with the two cables in close proximity.

Interaction Crosstalk

The crosstalk currents from a carrier repeater output into voice-frequency circuits in the same cable must be limited, since they crosstalk again into carrier circuits near repeater inputs and, consequently, are amplified by the high-gain repeaters. Intermediate circuits most responsible for crosstalk of this type are made up of combinations of pairs and phantoms and the sheath, i.e., longitudinal paths.

One case of crosstalk of this kind would occur if the same cable were used for carrier pairs transmitting in the same direction on both sides of a repeater. This is prevented by transposing carrier pairs from one cable to the other at each repeater point, as shown on figure 1.

A second interaction crosstalk problem is encountered at the common voice and carrier repeater points and involves coupling between cables as well as in the same cable. Here the coupling path is from carrier repeater outputs to intermediate circuits in the same outside cable, back into the common office over these intermediate circuits and then via office coupling to intermediate circuits in a second outside cable and from there to carrier repeater inputs connected to pairs in the second cable. Referring to figure 1, a set of noise (and crosstalk) suppression coils is encountered in this path. The high longitudinal circuit impedance of these coils minimizes this interaction crosstalk.

Far-End Crosstalk

Far-end crosstalk currents are subjected to line attenuation and amplification similarly to the main transmission currents, and do not have extra amplification as in the case of near-end crosstalk. Furthermore, far-end crosstalk currents due to couplings at different points along the line tend to arrive at the distant end of the disturbed circuit at the same time. Hence a considerable portion of the far-end crosstalk over the type-*K* frequency range, which occurs between circuits transmitting in the same direction in the same cable, can be neutralized by introducing compensating unbalances at only a comparatively few points, such as one per repeater section. The far-end crosstalk reduction problem is greatly simplified because phantom circuits are not used for carrier operation.

Theoretically, for the same precision of match between the impedances in the two directions at the balancing point, the crosstalk reduction would be about the same whether the balancing is done at an intermediate point or at either end of a repeater section. Balancing will be done at repeater inputs rather than at an intermediate point, such as the middle, because it is practicable to obtain repeater impedances matching the average line impedance sufficiently well so that the effectiveness of balancing is reduced only slightly.

Nature of Far-End Crosstalk Coupling

The coupling between two cable pairs in a short length may be represented by a mutual admittance and a mutual impedance. The former is due almost entirely to capacitance unbalance, which varies but little with frequency, so that its effect could be practically balanced out by means of a simple condenser. The latter, however, involves a complex mutual inductance of the form $M_a + j\,M_b$, because of the proximity effect of the wires of a pair and of other cable conductors.[1] As shown on figure 2, both components vary considerably with frequency; M_a on the average decreasing as the frequency increases while M_b in the general case is of negative sign and reaches a maximum value at 56 kilocycles.

Type of Balancing

To obtain maximum reduction in crosstalk it would be necessary to use a condenser for balancing the mutual admittance and an inductance coil for balancing the

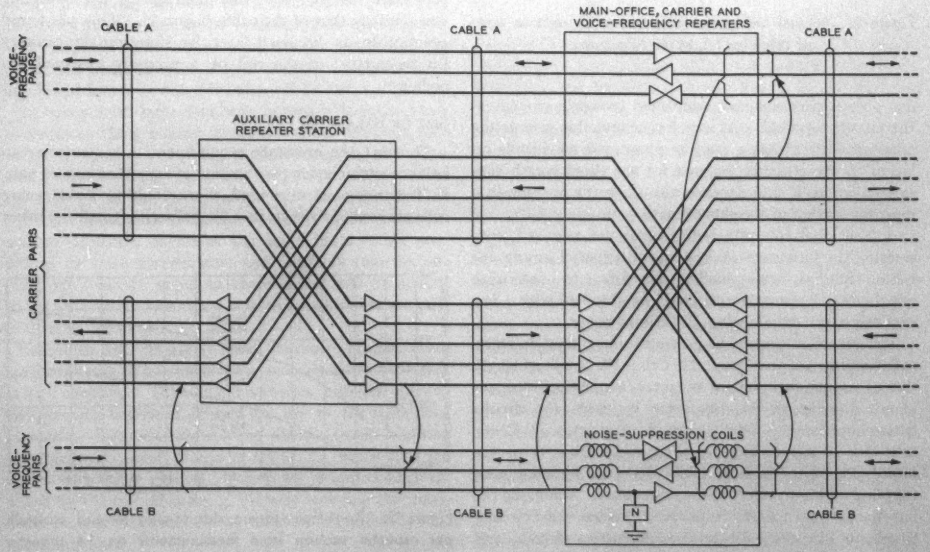

Figure 1. Schematic showing carrier pairs transposed between cables, coupling paths and noise suppression coils

mutual impedance or to use some equivalent complex network. Experimental balancing in a particular cable using the coil-condenser method reduced the mean crosstalk over the type-K range about 20 decibels, which is close to the maximum reduction possible with a universal type of balancing unit. The reduction is limited by the fact that two pairs having identical crosstalk couplings in each of two short lengths at different points in the cable will not produce two identical elements of crosstalk current at a circuit terminal because: (1) Cable circuits are not perfectly smooth. Reflections, as at junctions of reel lengths or at terminals, alter the two crosstalk currents differently. (2) The propagation constants of each circuit vary slightly from reel to reel in a random fashion and therefore the two crosstalk currents are of slightly different phase and magnitude. (3) In any short length the disturbing circuit produces crosstalk currents in intermediate circuits, which are propagated along these circuits and crosstalk again into the disturbed circuit at various points, producing an additional crosstalk current at the circuit terminal. At any frequency, this interaction crosstalk current has a random phase and magnitude relation to the crosstalk current for the short length considered by itself, and depends also upon the position in a repeater section of the short length.

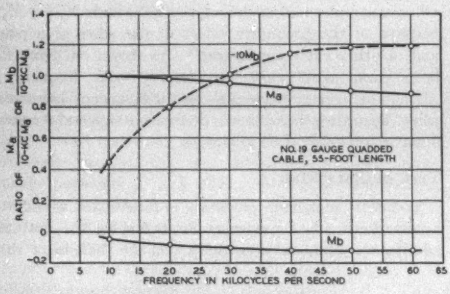

Figure 2. Mutual inductance between cable pairs in terms of value for M_s at ten kilocycles

A 20-decibel crosstalk reduction is not required, considering the number of K systems anticipated in any one cable. Studies were made, therefore, to determine whether satisfactory results could be obtained with a less expensive type of balancing, as outlined below.

The effects of frequency and circuit impedance on crosstalk coupling are as follows: (1) Crosstalk in a short length due to capacitance and to inductance coupling increases about directly as the frequency increases for circuits whose impedance is independent of frequency. (2) Crosstalk due to capacitance coupling varies directly as the impedance of the circuits while that due to inductance coupling varies inversely as the impedance. Changing the impedance from about 800 ohms for loaded voice circuits to about 135 ohms for nonloaded carrier circuits and changing the frequency from about four kilocycles to 60 kilocycles increases the crosstalk due to capacitance coupling by a factor of about 2.5 and that due to inductance coupling by a factor of about 90.

Capacitive coupling in existing cables was reduced by design to as great a degree as practicable, particularly for the most closely associated circuits, because it is of most importance in the loaded voice frequency case. These same design measures also reduce inductive coupling but not to the same extent. Capacitive coupling decreases rapidly with separation due to the shielding effect of copper in intervening circuits while inductive coupling is not much affected by intervening copper wires. To minimize magnetic coupling it is necessary to use different lengths of twist for the pairs. Existing cables have relatively few lengths of pair twists.

As the net result, capacitance coupling is no longer all important, inductance coupling at 60 kilocycles actually predominating by a factor of about three to one in existing cables. Capacitance balancing should, therefore, be less effective than balancing designed to reduce the inductance coupling. Tests have shown that capacitance balancing alone gives a crosstalk reduction of about 11 decibels while inductance balancing alone gives a reduction of about 16 decibels. Since the latter reduction is sufficient, except possibly for small cables or special cases, the type-K balancing has been designed on this basis. Far-end crosstalk currents due to the two kinds of coupling have phase relations not differing from zero or 180 degrees by more than about 15 to 40 degrees, depending on whether the upper or lower type-K frequencies are considered. There is, therefore, a tendency for either type of balancing unit to annul both kinds of coupling.

To obtain as much as 16 decibels reduction it is necessary that the frequency characteristic of the balancing coil simulate that of the cable (figure 2). This was found practicable, as discussed later, by shunting the primary (or secondary) of the coil by a properly designed impedance.

Size of Balancing Coil

To meet the crosstalk requirement it is necessary to balance each carrier pair against every other carrier pair. If 50 carrier pairs were used, there would be 49 balancing coils connected to each pair for balancing to all the other

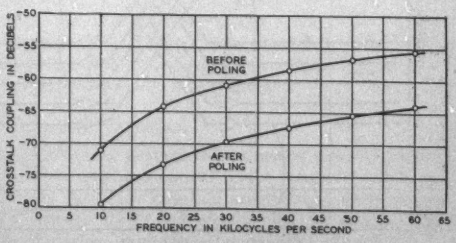

Figure 3. Root-mean-square side-to-side far-end crosstalk per repeater section from measurements on 14 repeater sections

pairs, a total of 1,225 coils. For convenience, adjustable coils having the same mutual-inductance range and the same self-inductance are used. Hence, the insertion loss per coil, resulting from the self-inductance and resistance of the coils, must be kept small. In addition, the self-inductance of the coil presents a problem from the impedance standpoint. To keep the impedance at any point in the balancing panel as nearly like the average cable impedance as practicable, the self-inductance of a series of coils must be neutralized by capacitances shunted at suitable intervals. It is very desirable, therefore, to use coils whose self- and mutual-inductances are no larger than actually essential. Consequently, an attempt has been made to keep the maximum crosstalk before balancing low.

Due to special measures, described below, it appeared that the maximum inductance unbalance per repeater section could be kept below about 1.3 to 1.5 microhenries, with the possible exception of side-to-side unbalances, and trial balancing coils were designed accordingly.

Crosstalk Reduction Before Balancing

Changes in the original splicing are made at approximately 6,000-foot intervals, i.e., at points where voice-frequency loading coils must be removed from the carrier pairs. In most existing voice-frequency toll cables the 19-gauge quads were spliced as three groups, one, a two-wire circuit group, one, an eastbound four-wire circuit group, and the third, a westbound four-wire circuit group. Ordinarily, the carrier pairs will be selected from the four-wire groups because these groups are usually larger than the two-wire group and since the quads within a group are spliced at random there is less chance of a large value of coupling between pairs of different quads, i.e., two pairs are less apt to be recurrently in a relation of high coupling. The carrier pairs are divided evenly between the two four-wire groups, in order that the least number of four-wire voice circuits will be lost.

In cables with large four-wire groups it is satisfactory to maintain the grouping arrangement on the pairs converted to carrier. In such cables, however, one four-wire group is in the center or core of the cable and the other group in the outer periphery. In order that all circuits will have about the same velocity and attenuation and be subjected to about the same temperature conditions for both transmission and crosstalk reasons, one (four-wire) carrier group in these cables will be spliced to the other (four-wire) carrier group and vice versa at the 6,000-foot intervals.

In cables with relatively small four-wire groups, there is more chance of two pairs being recurrently in a relation of high coupling. To reduce this chance, a special splicing arrangement has been devised for use at the 6,000-foot intervals. With existing splicing the maximum coupling in cables with small groups is about 2.5 times that for cables with large groups. This ratio is appreciably reduced by the special splicing, likewise reducing the maximum mutual inductance that must be supplied by the balancing unit.

The foregoing was with particular reference to crosstalk between pairs in different quads. Crosstalk between pairs in the same quad (side-to-side crosstalk) is an additional problem. A quad consists of two twisted pairs of wires which are twisted together to permit the use of voice-frequency phantom circuits. Since the two sides

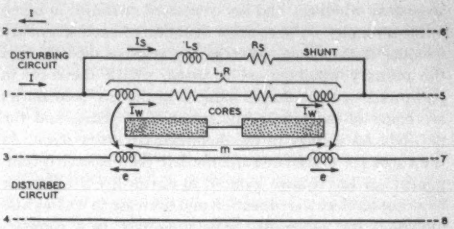

Figure 4. Schematic of a simple balancing coil designed to produce a complex mutual impedance

of a quad are so closely associated, side-to-side crosstalk is generally much greater than that between pairs of different quads. The electrical size of the balancing unit, therefore, is determined by the side-to-side crosstalk, which is reduced by "poling."

To apply poling, the quads are carried through as quads for an entire carrier repeater section. From measurements of side-to-side crosstalk in phase and magnitude, quads in one half repeater section are chosen and spliced to quads in the other half in such manner as to partially neutralize the side-to-side crosstalk. In effect, quads in one half-section serve as balancing units for the other half.

In most existing toll cables the side-to-side capacitance coupling was reduced when the cables were installed, by means of test-splicing within the 6,000-foot sections. Obviously, for poling to be effective it is necessary to operate mainly on the inductance component. The poling measurements, therefore, are made at about one kilocycle where an approximate measure of the inductance component can be obtained directly since the capacitance and inductance components of the crosstalk are at an angle of almost 90 degrees at this frequency. Figure 3 shows the crosstalk results obtained by means of one-kilocycle poling on 14 repeater sections. It has been shown that this 9-decibel reduction is within two to three decibels of the maximum reduction possible with much more complicated poling involving measurement and consideration of both components at carrier frequencies.

After side-to-side poling, coil balancing cannot be expected to give as much as 16 decibels reduction in crosstalk. This is unimportant, however, as long as the required reduction can be obtained more economically by the combined methods rather than by balancing alone.

Crosstalk Balancing Coil

Since the voltage which causes the crosstalk current in the disturbed circuit may be in either a clockwise or

counterclockwise direction, the balancing device, for flexibility reasons, should be capable of establishing voltages in either direction. A balancing coil was developed, therefore, which in operation may be likened to that of two separate transformers with simultaneously movable cores. The primary windings are in series, as are the secondary windings, and are connected as shown in figure 4, for example. The relative direction of each secondary winding is the same, whereas the relative directions of the primary windings are reversed. With the cores in mid-position, the voltages induced in the two secondaries are equal in magnitude but opposite in phase, and the net induced voltage in the disturbed circuit is zero. As the cores are moved toward the left the respective components of the voltage induced in circuit 3-7-8-4 increase in a counterclockwise direction and decrease in a clockwise direction, the net result being a voltage in a counterclockwise direction. Such a setting of the balancing coil would be used to counteract a clockwise crosstalk voltage, the amount of departure of the cores from mid-position being dependent on the magnitude of the crosstalk voltage being counteracted. Movement of the cores toward the right produces the opposite effect.

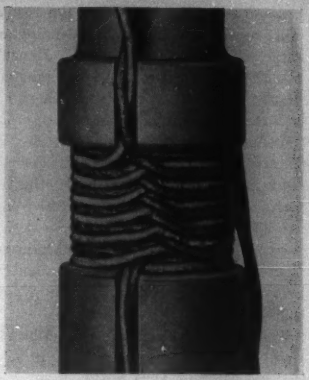

Figure 7. Arrangement of inner winding of trial balancing coil

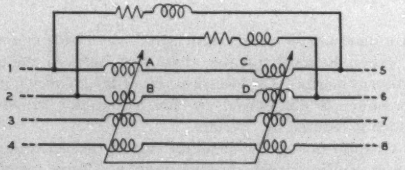

Figure 5. Schematic of winding arrangement of trial balancing coil

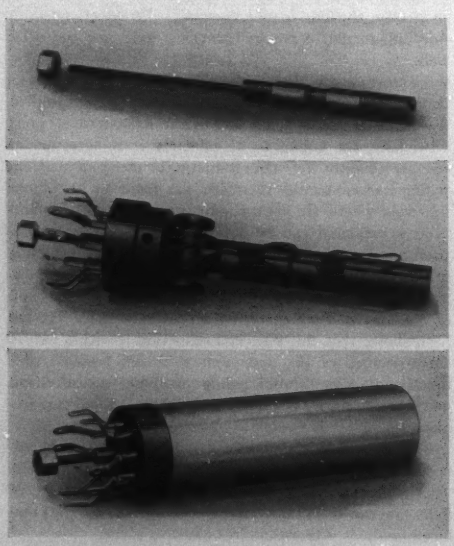

Figure 6. Trial balancing coil construction. Container is four and one-half inches in length and one and three-eighths inches in diameter

This device, disregarding any proximity effects therein and the effects of the shunt, acts to set up a net voltage e which is in phase quadrature with the disturbing current I. Hence,

$$e = -j\omega mI \tag{1}$$

in which m is the net mutual inductance of the device. To obtain the required mutual impedance characteristic, the primary (or secondary) windings of the coil are shunted by an inductive resistance. Let the effective self-inductance and resistance of the line windings (primaries) be denoted by L and R, respectively, and the current through these windings by I_w. Let the effective self-inductance and resistance of the shunt be denoted by L_s and R_s, respectively. At balance, that is, when no crosstalk current flows in 3-7-8-4 due to I (the disturbing current), the current I_w is

$$I_w = \left[\frac{R_s(R+R_s)+\omega^2L_s(L+L_s)}{(R+R_s)^2+\omega^2(L+L_s)^2} - j\frac{\omega(R_sL-RL_s)}{(R+R_s)^2+\omega^2(L+L_s)^2}\right] I \tag{2}$$

$$= [a - jb]\, I \tag{3}$$

where a and b are, respectively, the coefficients of the real and imaginary parts of the expression. Hence, with a shunted coil the voltage induced in the disturbed circuit is:

$$e = -j\omega mI_w = -j\omega(ma - jmb)\, I \tag{4}$$

The mutual impedance, Z_m, equals $j\omega(ma - jmb)$, or the effective mutual inductance M of the balancing coil may be written

$$M = M_a + jM_b \tag{5}$$

wherein $M_a = ma$ and $M_b = -mb$. Assuming R, L,

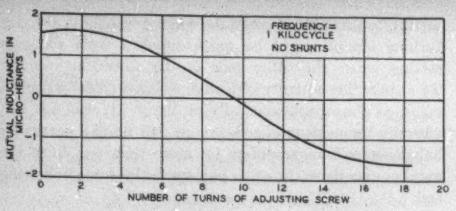

Figure 8. Mutual inductance of trial balancing coil

L_a, and R_a to be constant with respect to frequency of current and position of the cores, it is seen from (2) and (5) that for any core setting, M_a and M_b are functions of frequency only and their ratio at a given frequency is theoretically constant throughout the operating range.

To keep inductance L constant irrespective of the mutual inductance settings, the length of the coil windings, the length of the magnetic cores, and their spacings with respect to the winding spacing are so related that the change in inductance of one primary (or secondary) winding caused by motion of its associated core is equal and opposite to the change caused by the movement of the core associated with the other primary (or secondary) winding. To keep R low over the type-K frequency range, cores of finely powdered molybdenum permalloy pressed into a cylindrical form are used.

Because of other requirements which a balancing coil must satisfy, the winding arrangement actually employed is shown in figure 5. The simple device of figure 4 is not balanced from the standpoint of longitudinal crosstalk for any coil setting except that of zero mutual inductance. The figure 5 arrangement is such that theoretically there is no magnetic coupling between the two circuits for longitudinal currents in either one, regardless of the coil setting. Unless the capacitance between primary and secondary windings can be kept very small, the resultant admittance unbalance produces crosstalk which is not completely balanced out when the coil is adjusted. The turns of conductor in the figure 5 coil are so located that this side-to-side capacitance unbalance is less than five micromicrofarads. The capacitances between wires of either the primary or secondary winding do not affect the unbalance but contribute a part of the capacitance loading which compensates for the line inductance of the coils.

In the actual balancing coil, shown in figure 6, the windings are located in channels cut in a fiber tube which is secured to a head carrying the winding terminals and a bushing through which passes the threaded brass rod supporting the two cores. Below the head are small spool forms on which the shunts are wound. Insulating material such as bakelite is used to obtain proper spacing of the two cores.

The rather unusual manner in which the turns are applied is illustrated in figure 7, which is a close-up view of the two wires forming the inner winding. These two wires alternately cross over each other, progressing along the axis in opposite directions of rotation. The outer winding is similarly applied. This type of winding eliminates all splices within the coil, removing hazards incident to interior splices.

The complete coil assembly is enclosed by an aluminum container which serves the dual purpose of a shield and a convenient means of holding the coil for mounting purposes as this container fits snugly into an aluminum cup riveted to the assembly panel. The windings are dried and impregnated and the space between the coil assembly and container is filled with insulating compound.

The mutual inductance of a typical coil varies as shown in figure 8 as the cores are moved. The range, with the shunts disconnected, is approximately $+1.6$ to -1.6 microhenries, which is covered in about 16 turns of the screw (a total core travel of 0.5 inch). With the shunts connected, the effective mutual inductance at a given set-

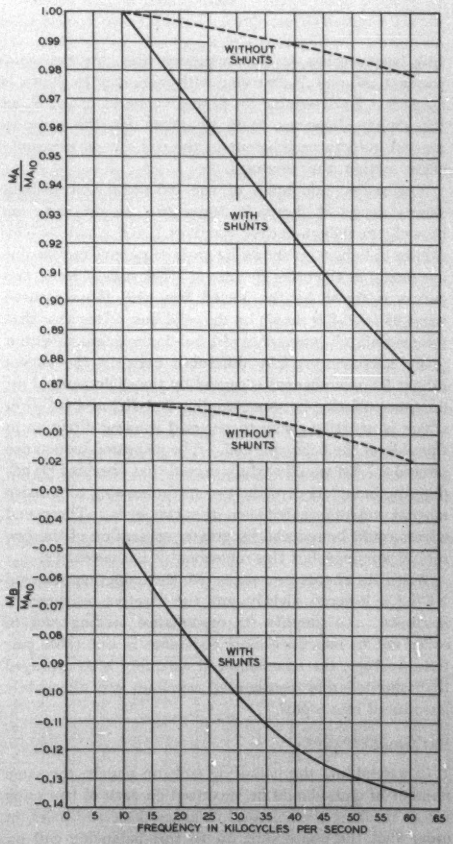

Figure 9. Variation of M_a and M_b components of trial balancing coil with frequency

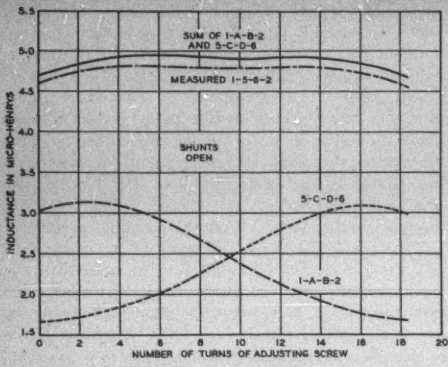

Figure 10. Series inductance of nonshunted trial balancing coil

ting becomes less as the frequency rises, the two components, M_a and M_b, varying with frequency as shown in figure 9. To determine the proper values of L_s and R_s for the shunt, allowance must be made for the complex mutual inductance inherent in the coil due to proximity effect within the windings.

The series inductance of the balancing coil without shunts varies as shown in figure 10. As the cores are moved, the inductances of windings 1-*A*-*B*-2 and 5-*C*-*D*-6 (figure 5) behave as shown by their respective curves, one increasing as the other decreases. The sum of these two curves is shown by the dotted line, and the measured value of 1-5-6-2 is shown by the solid line. It is seen that the over-all self-inductance of 1-5-6-2 is constant to within ±0.1 microhenry. The difference between the curves (about 0.1 microhenry) is caused by the slight mutual inductance existing between winding 1-*A*-*B*-2 and 5-*C*-*D*-6, which is negative owing to reversed winding direction in this side of the balancing coil. The measured inductance around 3-7-8-4 would slightly exceed that obtained by adding the inductances of the two sections owing to positive mutual inductance between the two ends. These end effects could be reduced by greater separation of the two sets of windings, but this refinement is not necessary.

When the shunts are connected, the inductance around 1-5-6-2 is lowered slightly, and the effective resistance is increased. To simplify the capacitance loading and in order not to introduce more resistance in one cable pair than another, the balancing coil assembly is so arranged that shunted and nonshunted windings are alternately introduced into a pair.

Balancing Panels

In assembling the balancing coils on panels, the same number of coils should be traversed on each of two pairs before reaching the coil that balances these two pairs, in order that the phase shift up to this balancing coil on one pair will be essentially the same as that on the other pair. If these phase shifts differed materially, the coil setting for minimum crosstalk when one pair is the disturbing circuit might be quite different from the best setting when the other pair is the disturbing circuit. To obtain this equality objective a "criss cross" arrangement, as shown schematically on figure 11, was devised, whereby the number of coils on one pair up to a particular balancing coil never differs by more than one from the number of coils on the other pair up to this same balancing coil.

For economic reasons it is undesirable to install a complete panel for the ultimate number of pairs, possibly 100

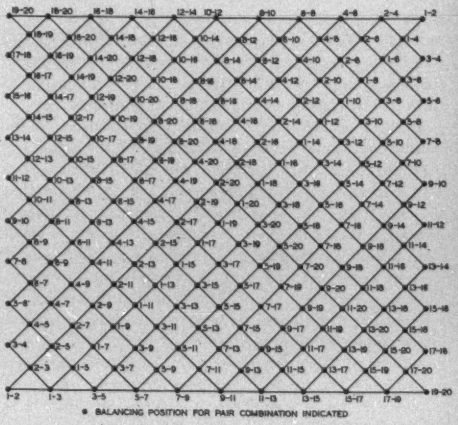

Figure 11. Schematic of criss-cross wiring for 20-pair balancing panel, designed to maintain phase equality of coils

in some cases, but rather to install sections conforming more closely to the circuit growth. The placing at different times and properly connecting of sections obtained from the 100-pair criss-cross panel and at the same time maintaining service on operating circuits appeared rather formidable. This problem was solved by the use of two types of criss-cross panels; an intragroup panel for balancing within one group of carrier pairs and an intergroup panel for balancing pairs in one group against pairs in a second group of equal size. In the present design, an intragroup panel takes care of 20 pairs (190 combinations) and an intergroup panel of the 400 combinations between two 20-pair groups. To maintain phase equality through a number of panels, it is necessary to install them following a definite pattern. Figure 12 shows a suitable pattern for the 15 panels required for 100 pairs.

In the criss-cross scheme (figure 11) the side-to-side combinations, which are those marked 1/2, 3/4, 5/6, etc., appear twice, i.e., along the left and right edges of the panel. Advantage of this is taken by installing balancing coils at both locations. This is done because one side-to-side coil of about 1.3 microhenries may not be large enough in all cases in spite of the fact that the mean

side-to-side crosstalk has been reduced nine decibels by poling.

Balancing Procedure

As stated above, the far-end crosstalk in a repeater section cannot be balanced out completely over the frequency range with a single balancing unit. To determine the balanceable as distinct from the nonbalanceable crosstalk, involves crosstalk measurements in phase and magnitude at a number of frequencies, using each pair of a two-pair combination as a disturbing circuit in turn. The balanceable crosstalk may then be separated from the nonbalanceable crosstalk by computation. Balancing by this method would be impracticable because of the time required. As a practical scheme, it has been shown that balancing at a frequency of about 40 kilocycles will produce satisfactory results over the type-*K* range even though part of the nonbalanceable crosstalk may be neutralized at this frequency. This is theoretically undesirable since the crosstalk reduction at other frequencies is impaired.

To prevent undue interference into operating carrier circuits when balancing, a frequency falling between the transmitted bands must be used. For this reason, the balancing coils are adjusted at a test frequency of 39.85 kilocycles and a measurement to check the suitability of the adjustment is made at 28.15 kilocycles. Figure 13 shows the crosstalk versus frequency before and after coil balancing by this method on three repeater sections.

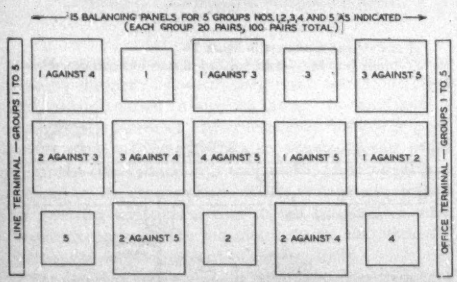

Figure 12. Allocation of balancing panels designed to maintain phase equalization of coils at all stages. Panels with suitable cross-connections between them are installed in following order

For first group—Install 1
Add second group—Add 2, and 1 against 2
Add third group—Add 3, 1 against 3, and 2 against 3
Etc.

Additional Crosstalk Remedial Measures

Although poling as well as balancing is done to reduce side-to-side crosstalk, this crosstalk is still considerably greater than the pair-to-pair crosstalk. For this reason, side-to-side crosstalk is diluted among the pair-to-pair combinations by a system of quad splitting at repeater points.

The crosstalk after balancing (figure 13) is considerably higher at the upper end of the frequency band than at the lower end. Consequently, if circuits were set up to use the same channel throughout, the crosstalk in the upper-frequency channels would be materially greater than that in the lower-frequency channels. In order that all circuits may be equally satisfactory from the crosstalk standpoint, a system of special channel assignments in successive intervals, say 500 to 1,000 miles, can be used. This will tend to equalize both the crosstalk and the noise on all circuits, thus permitting a somewhat cheaper design than if each channel had to meet the crosstalk and noise limits by itself.

Noise

Besides babble (noted above) many other sources of noise need to be considered in cable carrier design. Figure 14, which shows the approximate magnitude of several of these if no means are taken to suppress them, indicates the noise at the end of a single 17-mile repeater section when amplified by a repeater whose gain equals the hot-weather line loss. Curve *A* shows the unavoidable lower limit of noise, that produced by thermal agitation of the electrons in the cable conductors and the repeater.[3] This amounts to about 2×10^{-17} watts per telephone channel per repeater section, at the repeater input. If there were no other noise sources, the repeater section length would necessarily be limited by this effect. Curve *B* shows the sum of thermal noise and noise due to the vacuum tubes in the repeaters, which is little in excess of thermal noise alone. The other three curves show noises of considerably higher magnitude which require suppression in order to arrive at an economical carrier system. Curve *E* shows the order of magnitude of noise on carrier circuits due to connecting open-wire pairs directly to noncarrier pairs in the outside cable near the carrier repeater input. The source of the noise is heavy atmospheric static of a magnitude experienced several times during the summer. The other curves show typical magnitudes of noise originating in the existing telegraph and voice frequency telephone plant; this is generated in existing repeater stations and transmitted by the noncarrier pairs to the outside cable where it is induced into the carrier pairs. Curve *D* rep-

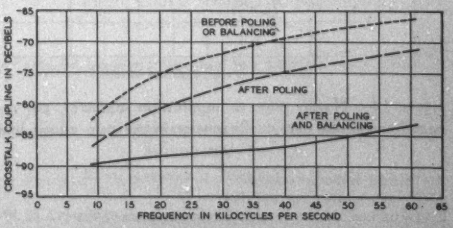

Figure 13. Root-mean-square far-end crosstalk per repeater section from measurements on three repeater sections

resents the situation at a combined telephone and telegraph repeater station, and curve *C*, the situation at a station where there are no telegraph repeaters.

Figure 15 indicates the results after suppression measures have been applied. As shown, at the top frequency, which controls the carrier repeater section length, these sources of noise have been reduced to be well below thermal plus tube noise. It is also shown that the noise due to heavy atmospheric static induced directly into a carrier pair in the outside cable is below thermal plus tube noise at the top frequency.

There are additional types of noise, not shown, whose sources lie within the carrier system: e.g., modulation in amplifiers, intersystem cross-induction, battery noise. While control of such noise is an integral part of the fundamental carrier system design, it is not the purpose of this paper to cover this class of noise.

Conductors Tapping the Carrier Cable

Carrier noise may come from open-wire pairs which connect to conductors in the cable. Its sources may be static; corona on power lines; power-line carrier or other carrier-frequency voltages on power lines paralleling the open wire; induction from radiotelegraph stations; or carrier frequency voltages arising in the office to which the open wire is connected, such as voltages generated by d-c telegraph or telephone signaling systems. The limited experience to date indicates that, in a long cable carrier system, the effect of heavy static will be larger than that of the other sources if telephone and power supply plants are co-ordinated so as to be satisfactory from voice frequency and low frequency standpoints. Branch cables connected to the carrier cable have a similar but generally smaller effect than that of open-wire taps.

Figure 16 illustrates the path followed by this induction. A voltage to ground impressed on the open-wire pairs passes by secondary induction over to the carrier pairs in the cable, and, on account of the unbalance to ground of these pairs, produces a metallic voltage on these pairs at the repeater input. The effect may be greatly reduced

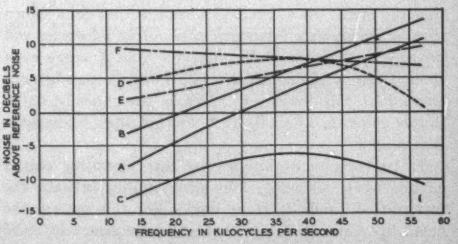

Figure 15. Noise, subsequent to suppression measures, per repeater section at output of repeater whose gain equals line loss

A to *E*—Same sources as in figure 14
F—Noise from heavy static induced directly into outside cable

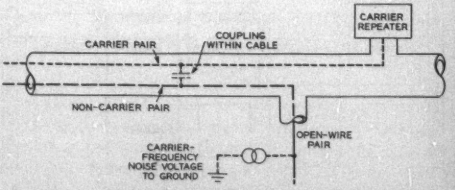

Figure 16. Schematic of path followed by induction from open-wire taps

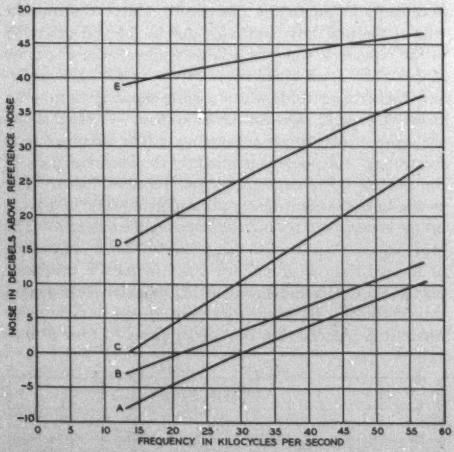

Figure 14. Noise, prior to suppression measures, per repeater section at output of repeater whose gain equals line loss

A—Noise from thermal agitation
B—Thermal agitation plus tube noise
C—Noise from voice frequency telephone repeater office
D—Noise from telephone and telegraph repeater office
E—Noise from heavy static on open-wire tap close to carrier repeater input

by interposing a filter at the junction of the open wire and the cable.

It is necessary to filter only the longitudinal circuit at an open-wire tap, because; (1) the voltage to ground on the open wire is much larger than the metallic circuit voltage, and (2) the coupling between the longitudinal circuit and the disturbed carrier pair is greater than the coupling between metallic circuits.

Figure 17 is a schematic diagram of the longitudinal filter developed for a phantom group. It consists of two longitudinal retardation coils and a set of condensers connected between the line wires and the cable sheath. This filter has relatively high carrier frequency longitudinal impedance to minimize effects of impedance in the ground

connection. The major portion of the carrier frequency impedance of the coils is obtained by designing them to have high core loss at these frequencies. The filter has little effect on voice frequency transmission, precaution having been taken to hold the transmission loss, crosstalk and unbalance to ground to low values.

Noise Arising in Existing Repeater Offices

The noise caused by carrier frequency voltages generated in existing repeater offices is due to d-c telegraph, telephone

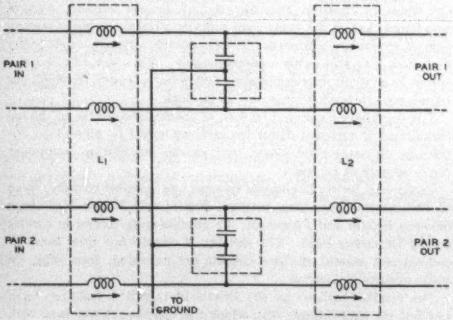

Figure 17. Schematic of longitudinal filter

speech and signaling voltages, power supply, etc. Figure 1 shows the path by which they reach the carrier plant and the means used to suppress them. In this figure, *N* represents a source of carrier-frequency voltage in a repeater office, connected to a voice frequency pair which transmits this voltage into the outside cable where it is induced on the carrier pairs. These voltages are reduced by inserting suppression coils in the longitudinal voice frequency paths at the junction between the office and the outside cable connected to carrier inputs.

The design of coils giving the requisite carrier-frequency suppression without appreciably affecting voice-frequency transmission on the circuits in which they are connected was difficult. One coil is used for each phantom group. Each coil has sixteen windings, four for each line wire. These windings are so paired and disposed about the core as to make possible very small side-to-side and phantom-to-side crosstalk between line windings. They also permit obtaining very small leakage flux in both the sides and the phantoms; hence the coils introduce very small transmission loss in their voice-frequency circuits. The leakage impedance of the coils plus the impedance of the cable stub used to connect them into the circuit is held down so that the effect on repeater singing and echoes in the voice circuits is very small. The coils are so wound that their longitudinal inductance is in antiresonance with their distributed longitudinal capacitance at approximately the top cable carrier frequency, resulting in a large increase in their suppression in this critical frequency range. The longitudinal impedance of one of these coils, and the

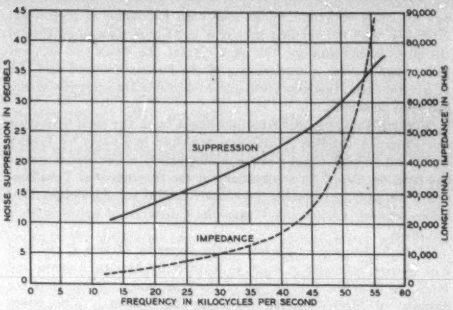

Figure 18. Longitudinal impedance and suppression of noise suppression coils

approximate suppression which a set of them provides, are shown in figure 18.

In addition, the carrier circuits are carefully separated, electrically and physically, from existing voice-frequency circuits in common repeater stations. To this end the carrier pairs in the outside cable are brought out on the line side of the noise suppression coils into a separate cable connected directly to a sealed terminal. From this terminal they are carried in shielded wire to the units in the carrier office and then to a similar sealed terminal leading to the outside cable in the opposite direction. Filters for filament and plate battery supply are included in the carrier amplifiers and additional filament battery supply filters are provided at the carrier fuse panels.

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2. **J. B. Johnson**, *Phys. Rev.*, 32, 97 (1928): **H. Nyquist**, *Phys. Rev.*, 32, 110 (1928).

Discussion

A Carrier Telephone System for Toll Cables

C. W. Green and E. I. Green

Cable Carrier-Telephone Terminals

R. W. Chesnut, L. M. Ilgenfritz, and A. Kenner

Crystal Channel Filters for the Cable Carrier System

C. E. Lane

Crosstalk and Noise Features of Cable Carrier-Telephone System

M. A. Weaver, R. S. Tucker, and P. S. Darnell

W. H. Capen (International Telephone and Telegraph Corporation, New York, N. Y.): The authors of this group of papers on carrier-cable developments should be highly complimented on the excellent presentation of this most interesting subject. Not many years

ago this type of system would have been impossible of production. However, with the vacuum tube now in its high state of perfection, the latest filter technique, the piezo crystal, the Black feedback amplifier, and a clear understanding of the factors involved and how to control them, this new economical telephone transmission system has been produced.

Working along parallel lines and based upon the early technique carried out by the Bell System and described in a paper by Messrs. Clark and Kendall (item 1 of the bibliography), a 12-channel system has been developed by a subsidiary of the International Telephone and Telegraph Corporation, and first installed for the British Post Office between Bristol and Plymouth, a distance of approximately 123 miles.

In the bibliography attached to the paper by Messrs. C. W. and E. I. Green, reference is made to a paper by Messrs. Angwin and Mack, published in the *Journal* of the IEE, and entitled, "Modern Systems of Multi-Channel Telephony on Cables." This paper includes a description of the English 12-channel system. As there are some differences between the British system and that described in the papers under discussion, a brief review of the Bristol-Plymouth system may be of interest. The system makes use of a frequency band extending from approximately 12 to 60 kilocycles with a carrier spacing of four kilocycles. Only the lower sideband is transmitted.

Separate cables are used for the "go" and "return" circuits and these were designed and installed especially for the application of the 12-channel system. Each cable is a paired cable; i.e., pairs were not twisted together in groups of two to form quads as is usual in voice-frequency cables. The chief advantages of this feature are that the higher couplings between pairs within a quad are avoided and that the effective resistance at 60 kilocycles for a given capacitance is less than in a quadded cable. However, future cables will probably be mainly of the star quad type because of the better space factor. Each cable comprises 19 40-pound pairs, which was the maximum number that would permit of the two cables (with special protection) being drawn into the normal three-inch duct lines. The outside diameter of each cable is 1.1 inches. Each pair was made with a different length of twist to minimize mutual impedance between pairs. To minimize increased resistance due to eddy currents induced in the sheath by pairs near the sheath, the lead sheath was spaced from the outer layer by a thick layer of insulation.

At 60 kilocycles the contribution of skin and proximity effects to the effective resistance of pairs in telephone cables tends to become the dominating factor when the wires are increased in diameter, and it was found that little advantage would be gained by increasing the gauge beyond 40 pounds per mile, which was decided upon. The maximum spacing of repeaters was fixed at 22 miles, with an average of 18 miles, corresponding to an attenuation of somewhat less than 60 decibels per repeater section.

In addition to the special design of the cable, it was, of course, necessary to balance the various pairs against each other in order to reduce crosstalk. It was found, however, that sufficient reduction could be obtained by the use of condensers alone. These were installed at the midpoint of each repeater section. By means of these condensers the average far end crosstalk was reduced from about 72.5 decibels to 85.5 decibels, while the maximum crosstalk was reduced from 63 decibels to 75 decibels.

The filters are of conventional design electrically, consisting of inductance coils and condensers. In view of the higher frequencies involved, the filter sections must be made more accurately than formerly, and so each arm of a filter comprising a coil and condenser in series (or in shunt) has been made into a unit and resonated to a predetermined frequency by means of a small variable condenser, before being assembled on the filter mounting plate. In this way the accuracy of the filters has been improved so that the characteristics of the highest channels are similar to those formerly obtained at frequencies not higher than 30 kilocycles.

The amplifiers follow closely the principles described by H. S. Black of the Bell Telephone Laboratories. A three-stage feedback amplifier is used, the feedback circuit being connected between the output of the last stage and the input of the first stage. A maximum over-all gain of 65 decibels can be obtained.

The over-all line characteristics taken at carrier frequencies on the whole repeatered circuit from Bristol to Plymouth showed a total variation, down to a frequency of 20 kilocycles of less than one decibel. The total variation of output level at any repeater station was found not to exceed two decibels over the range required for the 12 channels, and the over-all equalization was such that the effect on the frequency characteristic of any one channel was almost negligible.

In order to make some estimate of the effect of connecting systems in tandem, arrangements were made on one of the Bristol-Plymouth systems to loop back the channels on the two-wire sides. Using three channels in tandem, the quality as judged by ear was no different from that obtained on the normal circuit between Bristol and Plymouth. With six channels in series, the quality was still good but some slight deterioration could be detected. As a final test the whole 12 channels were looped back on one another, when it was found that, if the gains were suitably adjusted so as to give an over-all equivalent of three decibels, the speech, although considerably degraded, was still easily understandable. This last case is equivalent to a circuit approximately 1,500 miles in length, in which the signals pass through 96 repeaters in tandem.

The degradation referred to was, of course, due chiefly to the accumulation of terminal distortion and would not be present on circuits of the same total length with carrier modulating equipment provided only at its ends.

Equipment for six 12-channel systems was installed initially, three of the systems operating between Bristol and Exeter and three between Bristol and Plymouth; 31 circuits were placed in service during December 1936. The number of circuits has since been increased and several of these circuits are extended, four wire, on audio circuits to London.

The results obtained on the Bristol-Plymouth installation have justified the expectations with which the experiment was launched, and in the planning of the trunk network of Great Britain 12-channel carrier has already taken its place as the premier means of providing additional long circuits.

Plans are now actively under way for installing this type of carrier system on nearly all of the main routes from Plymouth in the south, to Aberdeen and Inverness in North Scotland. A total of nearly 17,000 two-way channel miles of this type of system are now in operation. Several thousand additional two-way channel miles are being installed, and further systems ordered.

Glen Ireland (American Telephone and Telegraph Company, New York, N. Y.): We are greatly indebted to the authors of this group of papers for this story about the development of the cable-carrier system.

The first commercial installation of the cable-carrier system in this country will be placed in permanent service between Detroit, Mich., and South Bend, Ind., a distance of about 200 miles, by the spring of this year. Other projects will follow and by the end of this year, cable carrier probably will have been applied along 830 miles of toll-cable route. Along about 560 miles of the route, the cable carrier will utilize conductors in two existing cables of the type previously placed for voice-frequency use. For the remaining part of the distance where only one such existing cable is available, a small paralleling cable of a special design is being provided. In connection with the engineering of these routes, it has been necessary to select the pairs most suitable for unloading and carrier usage, to survey the cables throughout to make sure that they were suitable in all respects and that necessary noise filters were provided for the open-wire and cable taps. Sites for 34 auxiliary repeater stations have been selected and suitable buildings of the type described in the Green and Green paper either have been or soon will be constructed. To the extent practicable, standardized equipment layouts are being provided in both the main and auxiliary repeater stations.

Cable carrier systems in the future are expected to find their principal field of use along the present long toll cable routes, where conductors in existing cables may be utilized and where there will be a demand for large numbers of additional circuits over 80–100 miles in length. A survey of the present toll cable network indicates that

there are some 2,900 miles of route having at least two cables and 6,500 miles of single-cable route that might be considered as potential candidates for the application of some form of cable carrier. Among the more important routes having at least two existing cables are New York-Chicago, Boston-Washington, New York-Buffalo, and Pittsburg-Terre Haute, Ind. The application of cable carrier to the existing toll cable network will be greatly aided by the fact that through previous standardization toll cable of known characteristics and quality and of a given gauge is available throughout the network. This is particularly important in connection with the crosstalk balancing work and the equalization of the high-frequency line.

The general introduction of cable carrier should result in marked improvement in the telephone toll service. Its availability, together with that of other broad-band carrier systems, has been one of the principal factors which makes it practicable for the Bell System to consider the introduction of improved transmission standards for the longer toll circuits. The greater velocity of transmission provided by the nonloaded cable conductors and the resulting reduction in delay effects are important factors in making this possible. The wider band of frequencies which are effectively transmitted by the cable carrier is also an important factor in improving transmission, this latter factor contributing materially to the naturalness and ease of conversation. The cable carrier systems also are expected to be very quiet. This is due in part to careful design and in part to the relative freedom of the high-frequency cable carrier circuits from the interfering effects of neighboring power systems.

Some of the maintenance arrangements mentioned in the paper are of considerable interest to the operating people. In particular the arrangement where amplifiers or a spare circuit link may be quickly substituted with little or no interruption of service is expected to be of considerable value to the field maintenance forces.

E. I. Green (for all authors): The authors have noted with interest the comments on the papers, particularly the discussion by Mr. Capen of the application of cable carrier between Bristol and Plymouth and elsewhere in Great Britain. As Mr. Capen has indicated, the British system follows to a considerable extent along the lines of the experimental system installed at Morristown, N. J., as described to the Institute in 1933, and differs in a number of respects from the present type-*K* system. The British system is applied to new cable installed underground. This cable is of special design and is nonquadded with 16-gauge conductors. The type-*K* system, on the other hand, is applied to existing cables installed either aerially or underground, and employs ordinary 19-gauge quadded conductors. The use of existing toll cables for the type-*K* system greatly augmented the problems of crosstalk and transmission regulation which had to be solved.

Harmonic-Current-Restrained Relays for Differential Protection

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DIFFERENTIAL relaying is the commonly accepted means of protecting large power transformers, a-c generators, and station bus systems against internal faults.[1] The methods and circuits employed in various instances, while differing in detail, are all fundamentally the same in basic principle. Briefly speaking, this principle consists in continuously comparing in each phase the current entering the protected equipment with that leaving. As illustrated in the generalized single-line diagram figure 1, the comparison is made by means of current transformers of suitable ratios placed in all the power circuits connecting with the protected equipment. If current transformation takes place within the equipment as in the case of a power transformer, the ratios of the current transformers placed in the various circuits are chosen to have relative values corresponding to the transformation ratios so that the current transformer secondary currents may be compared on a 1:1 basis. The secondary windings of all the current transformers in each phase are connected in parallel with each other to a special kind of current relay usually called a "differential" relay. The current transformers are all connected in the same polarity with respect to the direction of the protected zone so that currents entering and leaving the protected zone will be represented in the secondary circuit by currents of opposite polarities. Normally, with sound equipment these positive and negative components will be equal, except for negligible exciting currents, and their algebraic sum which by the connection is applied to the relay coil will be essentially zero. When a fault occurs within the protected zone, however, the balance is upset and a difference current proportional to the fault current flows in the coil of the relay, causing it to operate and trip circuit breakers in all the connecting circuits, removing the faulted equipment from service.

It is important that the faulted equipment be isolated as quickly as possible after the fault occurs, not only to limit damage to the equipment but also to minimize the length of time that the voltage is depressed. A prolonged period of low voltage is likely to result in loss of synchronism between rotating machines. When this occurs the excessive current drawn by the machines out of step often causes other protective relays to operate, tripping out circuit breakers until the power system is split apart and a major interruption of service results. A prolonged period of low voltage also results in loss of important loads due to operation of undervoltage devices. It is just as important that loaded equipment should not be needlessly cut out of service due to false operation of the relays when no internal fault is present. Unbalanced currents may sometimes flow in differential relay circuits when no internal fault is present due to causes which will be discussed below. These will cause false operation of the differential relay unless means are used to prevent it. The means hitherto employed and their shortcomings will be discussed, and a new method, free of these shortcomings, and suitable for general application will be described.

Paper number 37-171, recommended by the AIEE committee on protective devices and presented at the AIEE winter convention, New York, N. Y., January 24–28, 1938. Manuscript submitted October 28, 1937; made available for preprinting December 13, 1937.

L. F. KENNEDY is employed in the relay engineering section of the General Electric Company, Philadelphia, Pa., and C. D. HAYWARD is development engineer for the same company.

1. For all numbered references, see list at end of paper.

Causes of False Differential Currents

A. Departure of Current Transformer Ratios From Their Normal Values

When heavy current, due perhaps to an external fault, is drawn through the equipment protected by differential relaying, the current transformers become saturated and their ratios depart from their normal values by an amount depending on their designs, the amounts and power factors of their secondary burdens and the magnitude of the fault current. With full rated burden connected to the current transformer secondary and with currents of 20 times normal load value passing through the primary the ratio change may be so serious that only half the current calculated from the normal ratio flows in the secondary circuit. With lighter secondary burdens or lower values of primary current the departure is less severe but still considerable. In the special case where only two current transformers are involved, if the characteristics are matched, the secondary current sum will still be zero and no difference current will flow in the relay. With more than two current transformers, however, differences in the current-transformer characteristics or unequal distribution of the primary currents between the several current transformers will cause a difference current to appear which tends to operate the relay.

The usual method of preventing relay operation on differential currents due to current transformer saturation has been to use what is known as a "percentage differential relay." This type of relay compares the differential current with the through current and requires that the differential current exceed a certain percentage of the through current before the relay operates. This is accomplished by connecting a restraining coil in the relay in series with each of the current transformer secondaries. This type relay has been widely and successfully used on a-c generators and on two- and three-winding transformers.[2] Where only two circuits are involved, as in the case of the generator and the two winding transformer, the relative directions of the currents in the two current

transformer secondaries is always the same when the equipment is sound, so both restraining coils may be placed on a single restraint magnet acting on the armature. In the general three-winding transformer where the relative direction of current flow in the three windings may be different under different conditions, it is necessary that the three restraint coils be placed on three separate magnets acting on the armature separately. Where more than three windings are involved or similarly in the case of bus systems where there are many circuits, it has not been found practical to use this type of relay because of the complications involved in building a relay with so many restraint magnets.

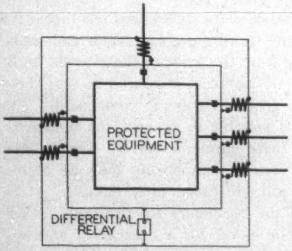


Figure 1. Fundamental circuit for differential relay protection

B. Magnetizing Inrush Current in Power Transformers

It is a well-known fact that when a switch is closed, suddenly applying potential to a winding of a previously de-energized transformer, the transient magnetizing current which flows may for a time reach very high values depending upon the amount of residual magnetization left in the transformer core from former operation and upon the point of the voltage wave at which the switch is closed.[3] In comparison with normal steady-state magnetizing current which for large power transformers is in the neighborhood of one per cent of full-load current, this transient magnetizing inrush current often reaches values of eight to ten times full load current (800 to 1,000 times normal magnetizing current). This magnetizing current flows in the transformer primary winding only and hence causes a corresponding difference current to flow in the differential relay.

The tendency of differential relays to operate on magnetizing inrush currents in power transformers has been resisted in the past either by using a slow acting relay, or by desensitizing the relay (or rendering it altogether inoperative) during a definite time following the application of potential, thus enabling it to ride over the magnetizing inrush period. This latter means has been accomplished by the use of a time-delay voltage operated auxiliary relay energized from a potential transformer connected across the power transformer winding and having contacts connected to remove a shunt around the operating coil (or to close a trip circuit contact in series with the differential relay contacts). Both these methods are unsatisfactory when judged by the standards of modern protective relay practice, the first because of its slowness on internal faults and the second because of the length of time that reduced protection is given the equipment. Cases are often encountered, particularly in large 25-cycle transformer installations where the inrush transient period may last for several seconds. Considerable damage can be done both to the transformer and to the system stability if a fault already present in the transformer when potential is applied is allowed to remain on for this length of time. Another objection lies in the failure of this method to prevent operation of the differential relay in cases occasionally encountered where magnetizing inrush currents appear when the transformer voltage, after being momentarily depressed by a close external fault, suddenly rises again as the fault is cleared.

C. Magnetizing Inrush Current in Current Transformers

Magnetizing inrush currents of considerable magnitude may also appear in current transformers. Heavy currents suddenly drawn through current transformers previously carrying little or no current cause magnetizing inrush currents to flow in much the same way as the sudden application of potential does in the case of power transformers. The magnitude of the inrush current depends upon the design of the current transformer, the magnitude of the fault current and the amount of secondary burden as well as the point of the wave at which the heavy current begins to flow and the amount of flux present in the core at that time. This inrush current flows in the primary of the current transformer only. The secondary current appears as a transformation of the primary current with the inrush current subtracted. In the differential relay connection the several current transformers will in general draw varying amounts of inrush current on through faults so that a difference current due to this cause will often flow in the relay.

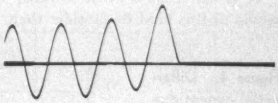


Figure 2. Differential current due to an internal fault

Figure 3. Differential current due to saturation of current transformers on heavy through fault current

Where the percentage differential relay may be used, as in the case of a-c generators and two- or three-winding transformers, the chance of having false relay operation due to current transformer magnetizing inrush currents is reduced by the use of a liberal percentage of through current restraint. This is not altogether satisfactory, however, since it reduces the sensitivity of the relay to in-

ternal faults. In applications where the use of a percentage differential relay is impractical, as in the case of many winding transformers or busses involving many circuits, the only recourse has been to the use of relays set for high pick-up current or to operate slowly enough to ride over the inrush period. This system of course leaves much to be desired.

Harmonic Current Restraint

A new method of preventing the false operation of differential relays on unbalanced currents due to any or all the causes described above has recently been applied. We have called it the principle of harmonic current restraint. It takes advantage of the difference in wave form between the differential current caused by a true internal fault and that caused by current transformer saturation or magnetizing inrush currents to restrain the relay from operating except when a fault exists within the protected zone. Oscillograms illustrating typical wave forms of these various currents are shown in figures 2, 3, and 4.

It is convenient when working with non-sine current waves of this kind to consider them as being composed of

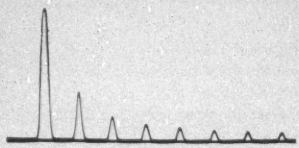


Figure 4. Differential current due to magnetizing inrush to either power or current transformer

an infinite series of sine wave components of ascending order of frequencies according to the Fourier expansion:

$$I(t) = I_0 + I_1 \sin(\theta_1 + wt) + I_2 \sin(\theta_2 + 2wt) + I_3 \sin(\theta_3 + 3wt) + \ldots$$

where

$I(t)$	=	the given non-sine wave current, varying as a function of time.
I_0	=	the constant or direct-current component.
$I_1, I_2, I_3, \ldots$	=	the maximum values of the fundamental, second harmonic, third harmonic, etc., sine-wave current components.
$\theta_1, \theta_2, \theta_3, \ldots$	=	the phase angle position of the various component waves at the time $t = 0$.
w	=	$2\pi f$.
f	=	frequency of fundamental in cycles per second. For the waves we are considering this will be the power line frequency.

A number of methods for evaluating the magnitude coefficients $I_0, I_1, I_2, I_3, \ldots$, etc., as well as the angle coefficients $\theta_1, \theta_2, \theta_3, \ldots$, are available. Some of these employ graphical means,[4] others mechanical.[5]

Values of the magnitude coefficients computed for the first cycle of each of the waves shown in figures 2, 3, and 4 are given in table I. These are expressed in per cent of the magnitude of the fundamental frequency component. For comparison the crest value of each of the waves in per cent of the crest value of its fundamental component is also given.

While it is understood, of course, that these percentages will vary when the conditions under which the currents appear vary, still for the purpose of our present discussion they may be regarded as typical. The wave due to an internal fault is shown having a rather large displacement, due to the point of the wave at which the fault was initiated. With a symmetrical wave the analysis would show 100 per cent fundamental with zero direct current and negligible harmonic current components.

It will be observed that the waves of the currents which cause undesired operation of the differential relay, that is, currents due to current transformer saturation and magnetizing inrush, differ from the wave of the internal fault current for which relay operation is desired in that they contain considerably greater harmonic components. In a practical relay it is possible to prevent the undesired operations by using these harmonic current components for restraint. The various components may be segregated by means of suitable tuned filter circuits. It is preferable to use all the harmonics for restraint, rather than to select any one alone, for a number of reasons. First of all, it will be observed from Table I that in the two different types of waves for which restraint is desired, different harmonics predominate. Hence, a relay designed to restrain on the second harmonic component only, for example, while suitable for magnetizing inrush currents, would not be properly restrained on currents obtained from saturated current transformers. On the other hand, if the relay were made to restrain on third harmonic only, proper restraint would be obtained on saturated current transformer currents but not on magnetizing inrush. The use of the d-c component alone would not be satisfactory because this component is absent in the saturated current transformer current and also because this component may be lost even on magnetizing inrush waves due to cancellation between phases when the current transformers in a wye-delta power transformer are connected delta-wye, as is the usual practice. Fur-

Table I. Harmonic Wave Analyses of Typical Currents Appearing in Differential Relay Circuits Due to Various Causes

		Differential Current Due to:		
	Wave Component	Internal Fault Figure 2	Saturated C. T.'s Figure 3	Magnetizing Inrush Figure 4
I_1	Fundamental	100 per cent.	100 per cent.	100 per cent
I_0	Direct current	38 per cent.	0 per cent.	58 per cent
I_2	Second harmonic	9 per cent*.	4 per cent.	63 per cent
I_3	Third harmonic	4 per cent*.	32 per cent.	22 per cent
I_4	Fourth harmonic	7 per cent*.	9 per cent.	5 per cent
I_5	Fifth harmonic	4 per cent*.	2 per cent.	34 per cent
I_6	Sixth harmonic	6 per cent*.	1 per cent.	4 per cent
I_7	Seventh harmonic	2 per cent*.	3 per cent.	3 per cent
	Wave Crest	145 per cent.	126 per cent.	244 per cent

* NOTE: It may seem surprising to those used to thinking of an offset fault current wave like figure 2 as being composed only of fundamental frequency plus an exponentially decaying direct current to see small quantities of the harmonics listed. This is because the d-c component is assumed by the analysis to have a constant value. The harmonics represent the exponential variation of the d-c component from the beginning to the end of the cycle. Expressing the analysis in this manner is proper because it is the way that the wave appears to the tuned filter circuits of the relay.

thermore, the use of the d-c component alone would result in a relay slow to operate on internal faults where the current wave is appreciably offset.

Practical Application—A Bus Differential Relay

A practical relay with harmonic current restraint, intended primarily for bus differential service is shown in figure 5. The operating characteristics of this relay are as follows:

Pick-up = 5 amperes on sine-wave 60-cycle current.

Operating time = one cycle average (60-cycle base) at twice pick-up or higher.

Burden = 1 volt-ampere at 5 amperes.

This relay was designed with the relatively high 5-ampere pick-up in order to avoid operation of the relay on normal load current in case one of the current transformers in the differential connection should inadvertently have its secondary open circuited. Bus faults invariably draw high enough currents to make extreme sensitivity unnecessary. The internal circuit is shown in figure 6. In this circuit the differential current supplied to the relay is first stepped down by means of a small internal current transformer to a value readily accommodated by standard ratings of the capacitors and rectifier used in the relay.

Figure 5. Bus differential relay with harmonic current restraint

Across the secondary of this transformer two parallel circuits are connected, one including the operating coil of the relay and the other the restraining coil. The operating coil circuit branch contains a wave trap made up of a capacitor C_1 and a reactor L_1 in parallel. This trap is tuned to block the predominant harmonic frequency, while the over-all circuit including this trap, the operating coil of the relay and the reactor L_3, is tuned by the capacitor C_3 to have minimum impedance to fundamental frequency.

The restraining coil circuit branch has a similar wave trap made up of capacitor C_2 and reactor L_2 in parallel which is tuned to block fundamental frequency. The over-all circuit is untuned. The operating coil circuit branch therefore readily passes current of the fundamental frequency but blocks currents of the predominant and to a large extent the other harmonic frequencies. The restraining-coil circuit branch passes the harmonic frequencies with moderate impedance but blocks the fundamental. Sustained direct current is prevented from flowing in the relay coil circuits by the relay current transformer. Transient current surges may flow in the secondary circuits, however, due to the sudden application of the d-c component when the differential current starts. These current surges have comparatively steep wave fronts and hence pass through capacitors with little impedance. These surges divide between the operating and restraining coil circuit branches essentially in inverse proportion to the relative inductance of the two branches with all capacitors considered as being short circuited. Tests demonstrated that the addition of the reactor L_3 in the operating coil circuit prevents momentary operation

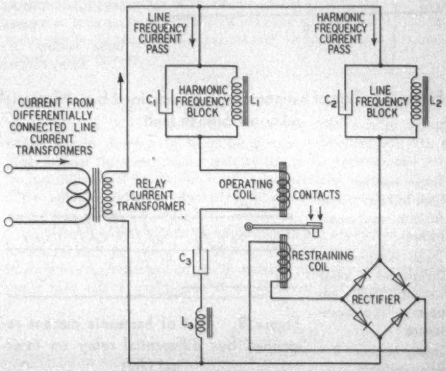


Figure 6. Circuit of differential relay with harmonic current restraint

of the relay due to these surges on magnetizing inrush currents. The restraint current, having an alternating wave of different frequency from that of the operating current, would, if unrectified, pass through zero at different times than the operating current. At these times the restraining pull would be released and the relay armature would tend to move by momentary flicks in the operating direction. Tests showed these flicks were often of sufficient magnitude to cause contact operation. The use of the rectifier aided by the inductance of the restraint coils was found to be effective in smoothing the restraint current and hence the restraint pull sufficiently to correct this trouble.

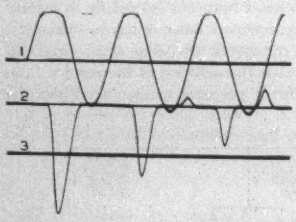
A differential current due to an internal fault, like figure 2, flows principally in the operating coil and hence

causes high speed operation of the relay. A differential current produced by current transformer saturation, like figure 3, or by magnetizing inrush, like figure 4, on the other hand will flow partly in the operating coil and partly in the restraining coil. The restraint magnet air gap is shorter than that of the operating magnet so that the restraint pull predominates and the relay does not operate.

Tests

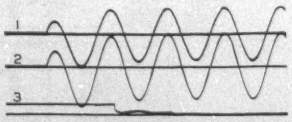
The relay shown in figure 5 has been thoroughly tested with successful results, under conditions closely simulating those found in actual bus differential relay installations. Two typical oscillograms are shown in figures 7 and 8.

The oscillogram in figure 7 was obtained on a setup representing a through fault. A current of 10,000 amperes root-mean-square was carried into a bus through two lines in parallel and out through a single line. Bushing-type current transformers of 600/5-ampere ratio, one in each of the three lines, were differentially connected to the harmonic current restrained relay. A resistance of three ohms was placed in series with the secondary of the current transformer in the single outgoing line. No burden other than that imposed by the relay and short connecting leads was placed on the other two current transformers. Trace number 1 on the oscillogram is the fault current derived from a shunt, trace number 2 the differential current flowing through the relay, and trace number 3 is of the current in the relay contact circuit. Even though the crest value of the first current loop shown on trace number 2 is 116 amperes, no relay operation occurred.



Trace number 1—Fault current, 10,000 amperes root-mean-square
Trace number 2—Differential relay current. Crest value of first peak = 116 amperes.
Trace number 3—Relay contacts

Figure 7. Test of harmonic current restrained bus differential relay on through fault



Trace number 1—Fault current, 7,200 amperes root-mean-square
Trace number 2—Differential relay current, 59.5 amperes root-mean-square
Trace number 3—Relay contacts

Figure 8. Test of harmonic current restrained bus differential relay on internal fault

The oscillogram in figure 8 was obtained on a set up representing an internal fault on the bus. This setup was similar to the one described above except that the outgoing current flowed through a line connected directly to the bus instead of passing through the third current transformer. The fault current as shown by trace number 1 was 7,200 amperes root-mean-square, the differential current as shown by trace number 2 was 59.5 amperes root-mean-square, while trace number 3 indicates that the relay operated and closed its contacts in approximately one cycle.

Conclusions

1. Differential relaying systems as used for the protection of large power transformers, a-c generators, and station bus systems are subject to false operation on differential currents due to causes other than internal faults in the protected equipment.

2. The means hitherto available to prevent false operation, while satisfactory in some cases, are either impractical or give reduced protection in others.

3. The use of the harmonic components of these currents for restraint is an effective and generally applicable means of preventing false operation while allowing complete, continuous and high-speed protection against internal faults.

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Discussion

J. H. Neher (Philadelphia Electric Company, Philadelphia, Pa.): I have had the privilege of watching this relay grow from just a good idea into its present form, and I wish to congradulate Messrs. Kennedy and Hayward on their development of this device and the excellent paper describing it.

The Philadelphia Electric Company was recently faced with the problem of obtaining a differential relay for the protection of the 220-kv bus sections at Plymouth Meeting having an operating time comparable with that of the high-speed relays employed on the lines, which was required by stability considerations, and which at the same time would be immune to operation by transient currents which might appear in the differential circuit on through faults. While high-speed overcurrent relays might have been employed with a sufficiently high setting to override these transients, there is no practical method of determining the maximum value which these transients may assume. It would seem, therefore, that the proper solution of the problem is not to try to guess the value of the transient, but to so arrange the system that the transient, if it appears, will act in such a way that the relay margin is increased rather than diminished thereby. The importance of correct operation of bus differential relays is usually such that the additional complication is well justified.

As a result of this reasoning, we have, or will have shortly, all of our 220- and 66-kv bus sections protected by means of the relay described. These installations are so recent, however, that no operating experience has been obtained to date.

Since both our 220- and 66-kv systems are solidly grounded, the

pickup value of the relay could be sufficiently high to make additional restraint against inequality of current transformer ratios unnecessary. If the relay is required to respond to single-phase-to-ground faults on systems where such fault currents may be limited, then a more sensitive relay will be required and its response to the differential currents produced by inequality of current transformer ratios on heavy through faults must be considered. While this type of relay can be constructed with percentage restraint in the usual sense, and the equivalent effect of as many restraining coils as are necessary can be readily provided, nevertheless this complication may not be necessary. The point is that when the secondary currents delivered by the current transformers reach such proportions that the differential current produced by their inequality may equal the normal pickup value of the relay, then these secondary currents may be so rich in harmonics that the effective pickup of the relay may be raised considerably above its normal value, and in effect, percentage restraint is automatically provided. I hope that the authors can give us further information on this point.

There is a unique feature of the relay which the authors have not mentioned and which may be of interest. In a number of differential relay installations, provision has been made for checking the state of balance of the differential system by an arrangement whereby the operator can insert a low range ammeter in series with the differential relays. In the case of the harmonic-restrained relay described, this same result can be achieved by an arrangement whereby the operator can connect a high resistance rectifier type voltmeter across the secondary of the current transformers contained within the relay. This arrangement is more desirable because the a-c connections to the relay are not disturbed.

R. M. Smith (Westinghouse Electric and Manufacturing Company, Newark, N. J.): This paper should be of unusual interest to relay engineers as it proposes one novel solution for the problem of high-speed protection of electrical equipment.

It is interesting to note that with the exception of the magnetizing inrush of power transformers, the problem of high-speed differential protection is made difficult only because of unfaithful response during faults of the current transformers connected to the protective relay. With proper attention paid to the factors affecting current transformer performance, many simple high-speed relays are available for differential protection, such as the percentage differential relay or even the ever-faithful overcurrent relay. Unfortunately most of the applications for existing equipment finds current transformers ill equipped to handle their burden during maximum through short-circuit conditions without one or more departing severely from true ratio.

The relay described in the paper is apparently adapted for bus differential protection only. The only problem here is saturation of one or more of the current transformers, thus producing current in the differential circuit on a through fault. As shown in figure 3 of the paper this current may be distorted and the relay apparently distinguishes between an internal and external fault by the ratio of the harmonic current to the fundamental. We fail to see why an internal fault will produce a differential current free from harmonics if one or more of the current transformers is saturated. It would appear that there must be some definite ratio in the design of the relay between the amount of fundamental frequency component tending to operate the relay and the harmonic currents tending to restrain the relay, which will produce a balance. In table I the analysis shows that for the differential current due to saturated current transformers there is 32 per cent third harmonic for 100 per cent fundamental for the particular case under consideration. We presume that much less than 32 per cent of harmonics will adequately restrain the relay from operating under this condition so that some safety factor will be provided. The question arises in case of an arcing fault on a bus, when the relay should trip, what per cent of the relay current will be harmonics due to the arc. It would appear that if harmonics were introduced by such an arcing fault in any appreciable magnitude, the relay would fail to trip. Since the paper states that the relay has been thoroughly investigated we believe that the paper would have been made more interesting if pertinent data representing cases of arcing faults had been presented.

The figures showing the test conditions show rather simple wave forms. It is to be noted that an almost infinite variety of wave shapes are encountered in such a differential circuit, depending upon the quality of the current transformers, the amount of short-circuit current and the amount and time constant of the d-c transient. Of this tremendous variety of wave shapes to be encountered quite a considerable variation from the values given in table I will be found. We presume that the entire field of possible ratios between the fundamental and the various harmonic components have been explored. Such an investigation should have produced enlightening data to determine in the design just how effective the restraining electromagnet must be in order to prevent the relay from ever operating on through faults. Data showing the percentage of harmonics in the differential current, which will accomplish this purpose, would then determine the percentage of harmonics which could be allowed in the case of an internal fault, without causing the relay to fail to trip, the harmonics being intruduced either through arcing faults, or saturated current transformers.

R. L. Webb (Consolidated Edison Company of New York, Inc., New York, N. Y.): The authors have described a relay system which should develop to have many useful applications. It is judged, from the paper, that the relay has so far been applied only for bus differential protection, using a nonsensitive operating point of five amperes to avoid incorrect operations if a current transformer should become open circuited.

While such a relay should be applicable to bus protection in some instances, such as, where it is desired to use existing current transformers having imperfect or poorly matched accuracy characteristics under high-current conditions, it would seem that its most fertile

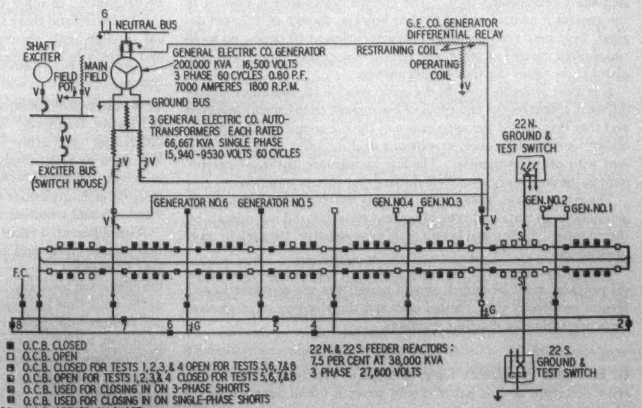

Figure 1. Short-circuit tests—number 7 unit, Hudson Avenue

field would be in the protection of rotating machines and transformers since high sensitivity is usually much more important in protecting such apparatus than in protecting busses.

The authors have pointed out some of the difficulties that must be overcome in applying differential protection to power transformers. We have come upon a type of phenomena found to exist in the secondary of current transformers used for generator differential protection which must also be taken into account when applying relays for this purpose. These phenomena make it appear that a harmonic restrained relay might easily be worked into a protective scheme for such a machine as this generator, but the restraint obtained from the harmonics would probably have to be quite high. It might be worth while considering the use of a small amount of fundamental restraint as well, when a relay of such sensitivity is built.

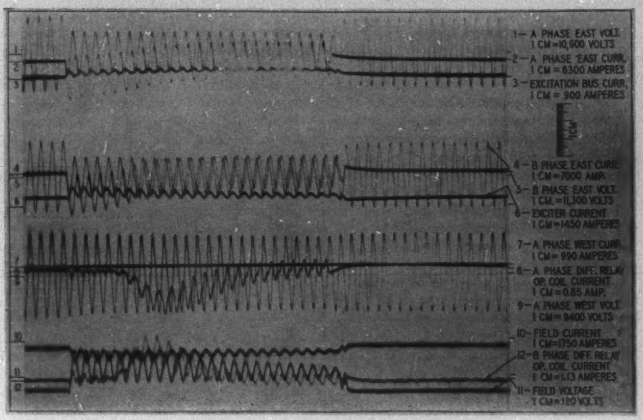

Figure 2. Number 7 unit short-circuit tests

A few years ago, some short-circuit tests were made on one of the later generators installed at Hudson Avenue Station. Oscillograph elements were connected into the operating-coil circuit of the percentage differential relays as a check on the current transformer characteristics for "through fault" conditions. Figure 1 shows the connections for the test. Both three-phase and single-phase faults were applied, beyond feeder reactors, with the machine operating alone at no-load and also when paralleled with the system and carrying a small percentage of rated load.

Figure 2 shows the results of the three-phase unloaded fault. Both *A* and *B* phase currents had a large d-c component. The effects on the *A* and *B* phase relay-operating-coil currents are plainly shown.

The results were similar to these for the single-phase-to-ground fault and for the tests made under light-load conditions.

In all of the cases, where the fault current had a large d-c component, it was noted that the relay-operating-coil current was rather high for a few cycles and had considerable 60-cycle as well as other frequency components in it. The current transformers, located in the generator neutral and at the bus breaker, though of different designs, have very good accuracy characteristics, at 60 cycles, up to 15 times rated current or more, and the current in these faults was only about three times the transformer ratings.

It is most probable that the d-c component in the fault current had different effects on the two types of instrument transformers involved and that this caused the appearance of the d-c component in the secondary current difference, as well as a healthy value of 60-cycle current with other harmonics. The late appearance of the d-c component in the secondary circuits is the basis for this assumption.

The relays in use, having a ten per cent differential operating characteristic with the usual type of current restraint, did not operate on these faults. If they had been a little more sensitive they might have functioned.

In any case, the use of harmonic restraint, even if some fundamental restraint must be added, should permit the use of relays having greater sensitivity than present ones and thereby give us more complete protection for machine windings.

G. B. Dodds (Duquesne Light Company, Pittsburgh, Pa.): The relay described in this paper should prove a useful addition to the protective-relay family, although some of us may prefer to use the standard percentage differential relays where applicable, for a while until we learn more about the harmonic restraint advantages and limitations.

As has been mentioned before, some of us have been wondering whether one-cycle relays are always desirable, and whether there is not frequently a desire for a two- or three-cycle delay. Of course, this can always be obtained by an interposing auxiliary relay.

In figure 7 is shown an oscillogram of fault current and differential relay current on a through fault. The fault current in this oscillogram is far from completely offset, and we are wondering whether tests were made with completely offset waves under this same current transformer and relay setup. From tests we have made, completely offset fault current adds enormously to the current obtained in differential circuits.

While the five-ampere relay will prove satisfactory in many cases, there are also frequent applications where a relay with lower operating current would be desirable; for example, where it is desired to have a fast ground relay in the neutral of the current transformers which must carry the magnetizing inrush to a large power transformer. In cases where the current-transformer ratio is large due to the size of the power-transformer bank, a one-half-ampere pick-up would be desirable. In other cases, where fairly sensitive ground protection is desired and there is danger of obtaining current by asymmetrical through fault currents, a harmonic-restrained relay with one-half ampere to one ampere sensitivity would be very useful.

T. W. Trice (Consolidated Gas Electric Light and Power Company of Baltimore, Baltimore, Md.): The introduction of a high-speed differential type relay unaffected by transients would indeed be welcomed by relay engineers. Methods heretofore used to prevent incorrect differential-relay operation generally result in delayed clearing of faults under correct operation when compared with the standards and requirements of modern relay practice.

With differential-relay installations the need for high-speed operation becomes more and more desirable as the magnitude of fault current increases. For example, a bus assumes greater importance as the connected load, and hence the possible fault currents increase, but at the same time high-speed fault clearing is essential to prevent serious damage and reduce system disturbance. This is an unfortunate condition, for while a reduction in relay time becomes more desirable with increased fault currents, it is necessary to approach high-speed operation with caution because it is more subject to incorrect operation than the slower relay settings. This leads to certain comments with regard to the relay introduced by Messrs. Kennedy and Hayward.

With reference to part *C* pertaining to magnetizing inrush current in current transformers, the authors' statements seem to discount the

fact that the current in the primary of a current transformer is determined solely by the load or fault current in the power circuit. The primary current in a series transformer is not determined by the excitation conditions as it would be in a power transformer connected across the line. In other words, a current or series transformer is subject to the magnetizing inrush current of the main circuit only and does not have a primary magnetizing inrush current of its own. Another statement in this paragraph—"the secondary current appears as a transformation of the primary current with the inrush current subtracted"—seems an obscure way of describing the fact that the secondary current of a current transformer is proportional to the primary current except when the primary saturates the core, in which case the inrush current above saturation cannot be reflected in the secondary. In view of this, we are somewhat in doubt as to just what the authors have in mind and would suggest that the phenomena associated with the so-called magnetizing inrush be clarified.

In the operating-coil circuit, tuned to pass fundamental frequency, within what limits of frequency will the circuit permit fundamental current to flow? While system frequencies are normally relatively stable, it is possible to have on the equipment or bus differentially protected, a frequency above or below normal, during or immediately following severe system disturbances, particularly if this part of the system has been separated. If the circuit is too sharply tuned, it is possible that the relays might remain inoperative on a fault occurring during this off-normal frequency period.

It is assumed that the relay is self-contained, not requiring field adjustments, all inherent parts being co-ordinated and assembled at the factory. However, the importance of reliability on differential protective installations dictates that relays used for this purpose should have periodic checking. In the case of a harmonic-restrained high-speed relay, it would seem of utmost importance to periodically reaffirm the effectiveness of the restraining circuit to prevent operation during transient conditions, particularly since the time of operation has been reduced to a minimum. While no difficulty should be encountered for checking correct operation on normal frequency, it appears somewhat difficult to check the restraining circuit to see that it continues to function properly on harmonic frequencies.

In this connection, some information as to the type of condensers utilized in the relay and the effect of temperature change and age on their performance should be of value. Furthermore, what effect will a condenser failure have on the operation of the relay? Having the relay completely inoperative under the condition of condenser failure, depending upon back-up relays for protection would seem to be more desirable than incorrect operation. If a faulty condenser could cause incorrect operation, there is even more reason why periodic checking of relays should be carried out. Likewise, a description of the rectifier used with information as regards its resistance to aging, is desirable.

It is believed that a relay of this type has a definite place in high-speed differential protection practice, particularly on new installations. However, it might be pointed out that there are many differential installations in use on systems throughout the country. From an economic standpoint, it would be highly desirable to modernize many of these installations by eliminating the delay features and reducing the over-all relay time. For this reason it is believed that attention should also be given to the development of a harmonic-frequency filter that could be externally connected to present differential relays.

E. L. Harder (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The satisfactory solution of a relaying problem involves the determination of a discriminating function or quantity which will adequately discriminate the desired trip conditions from the desired nontrip conditions, and then development of a relay element or structure which will respond to this particular quantity. These discriminating functions or quantities are of two general types. First are those which theoretically and practically separate the trip and nontrip conditions by a wide margin, preferably having zero value for the nontrip condition. Relays may then be built having corresponding operating characteristics and applied without any great amount of application effort. Ability to determine the necessary setting analytically is of considerable importance. The second type of quantity or function is that requiring statistical analysis to prove its ability to segregate the trip from the nontrip conditions. This empirical type of solution involves infinitely more application effort and proof of adequacy than the former. For it is necessary not only to show that in general a dividing line exists, but also to show for any individual application where that dividing line is. In other words, it is necessary to determine empirically at what value of the discriminating quantity the relay must be set.

In this particular instance the relaying quantity is of the statistical variety and consequently proof of its adequacy over the range of operating conditions is necessary. It will be of interest to point out the factors of variation affecting the proportion of harmonics present under various conditions. It is also important, as pointed out by the authors, that the relay does not actually respond to harmonics, as calculated from the wave forms by conventional methods, but rather has a response affected by harmonics but altered by the shock application thereof. The factors which would appear to affect the wave shape and hence operation of this type of element are as follows. Consider first factors tending to produce harmonics during internal faults (faults on the protected bus section).

1. The primary current wave shape. For internal faults harmonics may be accentuated by restriking arcs, system resonances, or circulation of harmonic currents between generators of dissimilar wave form. Such circulating currents may have high harmonic content.

2. Saturation of current transformers. During internal faults the largest harmonics would be expected with a critical degree of saturation, greater or less saturation resulting in lower harmonic content. The degree of saturation present is affected by the relay burden, length of leads, internal burden (or secondary leakage impedance) of the transformers, type of iron, iron section, length of iron path and turns, and the amount of a-c current and amount and duration of the d-c transient. These factors vary widely from one application to another.

The other condition of interest is that having maximum tendency to operate the relay when it should not be operated. This would require a differential current above the five-ampere setting with low harmonic content. Such a condition would be most likely to occur when heavy through faults cause a differential current in the relay but where saturation, and hence harmonics, are low. It may also occur at very severe saturation where the current transformers act nearly as air core devices over a fairly large part of each cycle. At intermediate saturations the restraint may be more favorable.

The root-mean-square of harmonics in columns 1 and 2 of table I are 14 per cent and 33.5 per cent. In view of this fairly close margin, for typical conditions, the margins under limiting conditions as mentioned would be of particular interest.

E. H. Bancker (General Electric Company, Schenectady, N. Y.): The conversion of an antagonist into an ally is an accomplishment worthy of remark. In this paper the authors tell how the aid of one of the chief obstacles to successful differential protection has been enlisted to bring about better performance. The inability of current transformers to maintain a constant ratio at high overcurrents has been a major hindrance to a wider adoption of bus differential relaying because it was feared that there was too great a hazard of losing busses for external faults.

It has been known for a long time that whenever current transformers saturate because of a d-c component in the primary current or because the a-c current is too large for the particular transformer with the particular burden, the magnetizing current is large and full of harmonics. D-c saturation produces a preponderance of even harmonics and a-c saturation chiefly the odd harmonics. It was also known that when the secondaries of several current transformers saturated to different degrees were differentially connected, the magnetizing current differences passed through the differential relay. It remained, however, for the authors of this paper to put these known facts to work for the good of mankind. The ingenious separation of differential currents into their fundamental and harmonic components and the use of the harmonic content for restraining operation make possible high-speed differential relaying without the attendant danger of unnecessary losing a bus or piece of equipment for some fault external to it. This marks another advance along the path that relaying usually follows, i.e., to recognize the peculiarities

and limitations of associated equipment and despite them all, to provide the required protection and service continuity.

Time alone will tell what other uses will appear for the harmonic restraint principle enunciated here. One is immediately apparent, transformer differential protection, where the troublesome harmonics arise from saturation in the power rather than in the current transformer. The application of harmonic restraint to transformer differential relaying will avoid the difficulties now existing in the use of high-speed relays for this purpose. Magnetizing inrush may be rendered innocuous without impairing the speed or sensitivity of the protection. Similarly, sensitive generator protection may be retained without the danger of false tripping or external faults having a large and slowly decaying d-c component.

H. P. Sleeper (Public Service Electric and Gas Company, Newark, N. J.): There can be no quarrel with the contention of the authors that the use of standard differential relays will tend to give improper operation on either bus or transformer differential protection because of the saturation of the current transformers or the sustained high charging current when a transformer is energized. However, the writer believes that it may not always be necessary to install relays of the types described by the authors of this paper to prevent such improper operation.

When straight differential relays, as compared with percentage differential relays, are used for such protection, the common way to avoid such a difficulty is merely to raise the trip-current settings. The apparent difficulty became increased when percentage differential relays were introduced, since the pick-up of these relays with one side de-energized is usually considerably lower than the normal setting of a straight differential relay. The obvious remedy is to merely increase the trip setting under these conditions. This applies to both transformer and bus percentage differential relays and ordinarily can be done without danger of failure since faults requiring the operation of such relays usually involve high values of power, and the operation of the relay elements under such fault conditions are accumulative, thus assuring positive operation.

It is recognized that the above suggestions are expedients only to take care of undesirable operating conditions. One of the simplest methods of preventing improper operation of percentage differential relays used for bus protection is to make certain that there will always be power in at least one restraining coil. This means that sufficient restraining coils must be present in the relays or certain current transformers must be paralleled to effect this result.

There is certainly a field for a differential relay which will not trip out a transformer bank incorrectly due to the inrush of magnetizing current when energized and yet will operate correctly and instantaneously when the protected unit becomes faulted. No such relay is on the market, to the writer's knowledge, which will or can be made to completely fulfill these specifications. If this new relay meets these specifications, the writer will be the first to cheer.

Since no characteristic curves of these new relays have been presented in this paper, it is impossible to analyze their operation; but it is the writer's opinion that the proper use of restraining coils, as in the manner described above, may still be required with the harmonic current restrained relays described in the Kennedy-Hayward paper.

L. F. Kennedy and **C. D. Hayward:** We feel very gratified indeed at the amount of interest aroused by this paper as evidenced by the unusually large number of discussions presented. The subject is apparently one of live and widespread interest. Since some of the points discussed were mentioned by more than one individual we think it better to review the discussion by topics rather than by the individuals presenting them.

Several questions were asked regarding possible fields of application. There seemed to be a feeling on the part of some that the harmonic restraint relay is intended only for bus protection. While the particular relay application described in the latter part of the paper was one of bus protection, still it should be understood that the harmonic restraint principle may just as readily be applied to relays intended for any other form of differential protection. As a matter of fact, the idea was first conceived for transformer protection. The recent interest in and demand for better bus protection lead to its first practical application being made in that field.

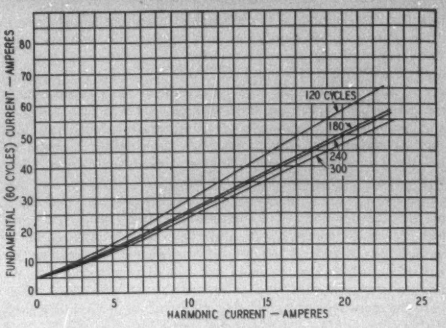

Figure 3. Harmonic-current-restraint characteristics of bus differential relay

Showing amount of fundamental-frequency current required to cause pick-up over the restraining effect of a given amount of harmonic-frequency current when the two are mixed in the input to the relay

Application to transformer and generator differential protection will require a relay having lower pick-up current than the five-ampere value required for the bus relay.

Some applications may require a certain amount of through current restraint in addition to the harmonic differential current restraint. This feature may be added by any of several means, for example, an additional restraining magnet energized by the through current might be used.

In regard to the question as to whether the high-speed operation is always necessary, we would like to give a very broad answer: If the reliability of a given type of protection is not impaired by high-speed operation, then high-speed operation is always desirable even though it may not be necessary. The necessity for high-speed operation usually arises from stability considerations but it is always desirable since it means reduced damage. We feel that with the harmonic-restraint principle the utmost reliability is obtained and that therefore the relay should be made to operate at as high speed as possible.

Several discussors asked for additional information on the operating characteristics of the relay, particularly as regards the percentage of harmonic restraint used and the effect of ordinary variations in the

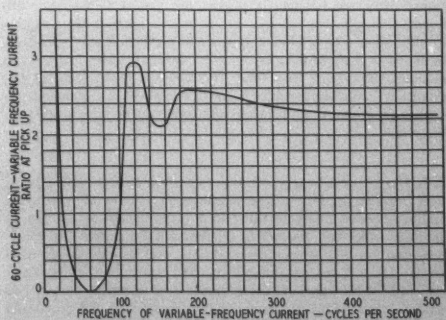

Figure 4. Restraint ratio versus frequency of current mixed with fundamental-frequency current

Slope of curves of the type shown in figure 3 plotted against frequency

system frequency. This can best be shown by reference to two additional figures. The curves in figure 3 were taken by mixing a current of a given harmonic frequency with current of fundamental frequency in the input to the relay. For each value of harmonic-frequency current the amount of fundamental frequency current to cause pick-up was determined. Curves for the second, third, fourth, and fifth harmonics are shown. The similarity of these curves to the slope characteristic curves of the familiar percentage differential relay should be noted. A small difference in the slope of the curves for the various harmonics is apparent. This is due to the characteristics of the filter circuits employed in the relay as is better illustrated by figure 4. Here the slope of the curve, that is the ratio of fundamental current to harmonic current required for pick-up, is plotted against the frequency of the harmonic. The shape and height of this curve may be modified by design if occasion demands it. The curve is fairly flat at 60 cycles, indicating that small variations in system frequency will have negligible effect on the pick-up.

Periodic testing of the relay after installation to check the effectiveness of the harmonic restraint can be accomplished by passing current of a known harmonic content through the relay. Such a current is readily produced by means of a suitable small portable saturating reactor. A measure of the degree of restraint can be obtained by simultaneously passing a variable amount of sine wave current controlled by a rheostat through the relay coil, mixing it with the current produced by the saturating reactor and observing the proportion of the two at pick-up.

The capacitors used are of the "pyranol" type while the rectifier is of the copper-oxide-disk type. Both are of the best quality and are energized only momentarily when a fault occurs. Under these conditions exceptionally long life is anticipated. Any possible deterioration with age would, of course, be detected by the periodic tests.

The possibility of incorrect relay operation due to harmonics produced in the primary line current by various causes such as line oscillations, circulating currents due to differences in generator waveforms and arcing faults has been suggested. First of all, it should be appreciated that any harmonic present in the line current in the case of an external fault, even assuming it was not entirely cancelled out in the differential connections of the current transformers, can only produce a small additional restraining effect on the relay, which is not undesirable. It seems unlikely that any large amount of harmonic current will be produced in the differential circuit in the case of an internal fault by any of these causes. At any rate, the examination of many oscillographic records taken under a wide variety of conditions fails to show any noticeable amount present due to these causes after the first cycle. From this it would seem that the worst effect these harmonics could have would be to delay tripping for at most a cycle.

The successful application of the harmonic restraint relay requires knowledge of the relay characteristics and of the current transformer performance. At the present time, detailed information regarding the harmonics produced by various types of current transformers under all conditions is incomplete. A program of investigation is under way to obtain this information as quickly as possible. Until this information is complete applications will have to be made with unusual care and will therefore require individual consideration.

Some Schemes of Current-Limiting-Reactor Applications

By F. H. KIERSTEAD
MEMBER AIEE

CURRENT-LIMITING reactors are so detrimental to the normal operation of an electric system, and yet such a valuable contribution to its safety during short circuits, that it is very much worth while to try again and again to devise schemes which will use the ability of reactance to limit fault current and yet minimize the inevitable increase in regulation. With this in view, this paper reviews some well-known schemes of reactor application.

It is hoped that in exciting discussion, not only of the few schemes described here, but also of allied schemes, a trend toward better current-limiting protection may develop. This paper is written from the viewpoint of a designer, and the author realizes that application and operation engineers may find valid objections to the suggested uses of the schemes discussed. The author feels, however, that the chief value of the paper to the art will not be in its contents, but will be in the discussion it may excite.

The following schemes will be discussed:

A. Reactors shunted by circuit breakers.
B. The saturable-core reactor.
C. The split-circuit reactor.

A. Reactors Shunted by Circuit Breakers

In order to alleviate the difficulty of opening a faulted feeder, it has been proposed to use two circuit breakers in series, the one with a shorter time delay being shunted with a reactor, so that when it opens its reactance is automatically inserted in the circuit—thus lessening the duty on the second "main" circuit breaker. Such a scheme can be operated successfully and, therefore, the economic aspects of it will be discussed below.

The interrupting duty on a breaker shunted by a reactor depends, among other things, upon the amount of reactance in shunt. The duty is reduced by the shunt reactor to the extent that the voltage across the breaker is reduced below that which it would have been if the reactor had not been present—in other words, to the extent that the recovery voltage is reduced by the presence of the reactor.

In order to evaluate the reduction in duty on a breaker affected by a shunt reactor, let us compare two 60-cycle, 6,800-kva, 13.2-kv cable feeders—one equipped in the conventional manner with a circuit breaker and a three per cent reactor, and the other equipped, in addition to the above breaker and reactor, with a breaker shunted by a reactor. These two circuits are shown in figure 1 and the pertinent circuit constants are given below.

Generator reactance (X_G) = 10 per cent and 20 per cent reactance on 50,000-kva base.
Series reactor (X_R) = 3 per cent reactance on 6,800-kva base.
Shunt reactor (X_S) = 15 per cent reactance on 6,800-kva base.

The final recovery voltage across the breaker of the conventional feeder and that across the shunted breaker of the proposed feeder are given below:

Generator Reactance	10 per cent	20 per cent
	Final Recovery Voltages	
Breaker in conventional feeder	100%	100%
Shunted breaker in proposed feeder	77%	71%

This table shows that the breaker shunted by the reactor must, in the cases assumed, be approximately three-quarters of the capacity of the breaker in the conventional feeder. The shunt reactor was chosen large so that the series breaker which finally opens the circuit could have a low interrupting capacity. This breaker, however, must have sufficient capacity to carry the initial current until the shunt breaker opens. Of course, if the reactance of the shunt reactor were made less, the breaker which it shunts could have smaller capacity, but the series breaker would then have to have greater capacity.

The series reactor could, in some cases, be made smaller where a shunt reactor is used, but this would result in higher current to be interrupted, and consequently in shunt and series breakers of higher interrupting capacity.

The table below lists the equipment required for both methods. The interrupting duty of each breaker is given in per cent of that required for the breaker of the conventional feeder. The short-time current capacity of the series breaker is neglected in this comparison.

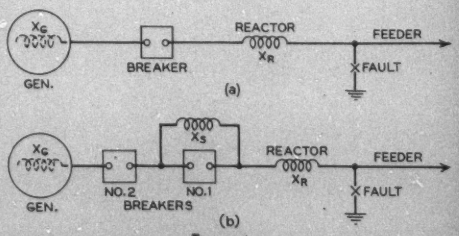

Figure 1

(a)—Diagram of the conventional feeder with a reactor and circuit breaker
(b)—Diagram of feeder same as (a) except an additional reactor shunted by a circuit breaker

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Actually this consideration may call for a breaker approaching 100 per cent in size.

	Reactors		Breakers	
	Shunt	Series	Series	Shunt
Conventional feeder	No	Yes	Yes—100%	No
Proposed feeder	Yes	Yes	Yes—25%	Yes—75%

Since the proposed feeder requires an additional reactor and breaker, it appears to be more expensive than the conventional feeder.

Considering the use of the "proposed feeder" from the standpoint of regulation, the series reactor might be reduced and thus improve the regulation. This would, of course, increase the current to be interrupted and, therefore, increase the required capacity of both the shunt and series breakers. The same reduction in the series reactor, and hence the same improvement in regulation, could be obtained in the conventional feeder by the use of a larger circuit breaker. It would appear that the same improvement in regulation would entail about the same increase in cost in each scheme, and that the conventional scheme would have the lowest cost in any case.

There seems to be no economic justification for the "proposed feeder" from either the viewpoint of cost or improvement of regulation.

There does, however, appear to be a very limited application for a circuit breaker shunted by a reactor in the case of a substation where the short-circuit kilovolt-amperes has grown beyond the capacity of the feeder circuit breakers. The feeder bus can be sectionalized from the source of power by a large breaker shunted by a reactor, and all the feeder breakers interlocked with the large breaker so that they cannot open until the large breaker opens, and then the breaker on the faulted feeder interrupts the fault current, which has been reduced to the capacity of the breaker by the insertion of the reactor.

Before such an application is made, thorough consideration should be given to the following factors:

1. Have the existing feeder breakers sufficient short-time current capacity?

2. Is the increased time required to open two breakers in succession (instead of one) with the consequent liability of greater destruction at the fault justified?

3. Is there greater liability of motors on the other feeders dropping out of step due to the longer time before the short is cleared?

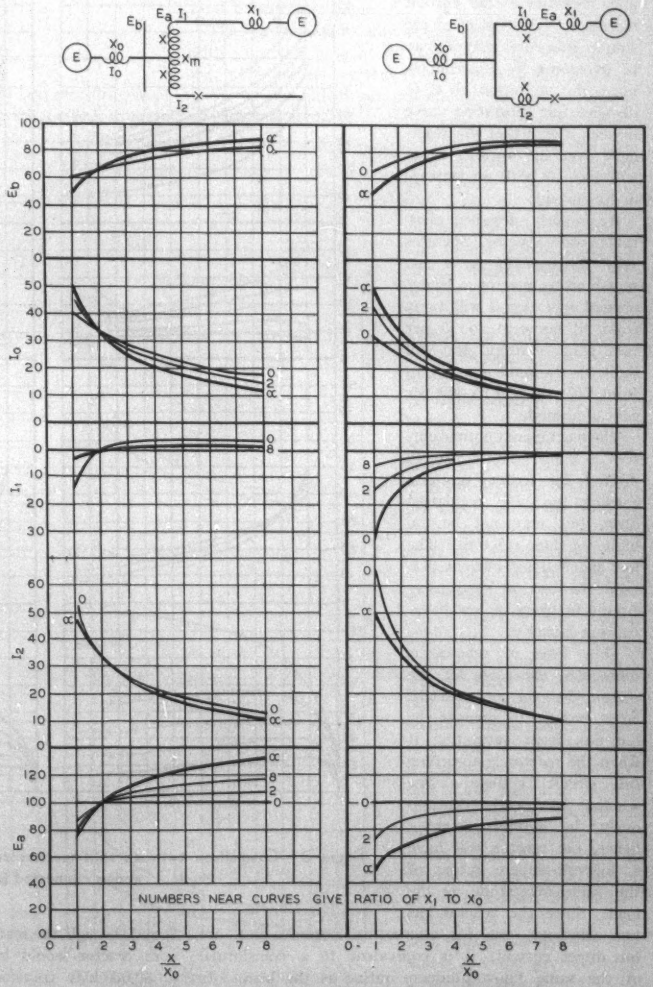


Figure 2. Comparison between split reactors and conventional reactors for feeder circuits. Feeders interconnected to other sources of power

In general, higher interrupting capacity breakers are a better solution.

B. The Saturable-Core Reactor

The inherent characteristic of an iron-core reactor is just the reverse of the desirable characteristic for short-circuit protection, in that its reactance *decreases* as the current increases. This defect of the simple iron-core reactor may be overcome by superimposing a d-c excitation[1] so as to displace the saturation curve in such a way that the reactance over the working range will *increase* with an increase in a-c current.

A properly designed saturable-core reactor operates very satisfactorily as a current-limiting reactor. Under normal operation it will insert from 10 per cent to 15 per cent reactive drop, and will limit short-circuit current to from 250 per cent to 350 per cent of normal.

The reactance at normal current is higher than is usually desired for feeder reactors, causing too high regulation drop, but may not be too high for bus reactors. The low short-circuit current permits the use of inexpensive circuit breakers of low interrupting capacity.

This type of reactor is inherently expensive for the reason that the core must be large enough to prevent the a-c flux from saturating it when the reactor is absorbing full circuit voltage. The winding must carry continuously the normal current—hence, the reactor will have a kilovolt-ampere rating of the same magnitude as the load. Since the reactor has two windings, one for alternating current and one for direct current, it is equivalent to a transformer of the same kilovolt-ampere rating as the load. In order to compare this type of reactor with the conventional air-core reactor, assume that the load transferred through the reactor is 30,000 kva. The saturable-core reactor would be equivalent in size and cost to a 30,000-kva transformer. If air-core reactors were used they would have 10 per cent to 15 per cent reactance, and since they have no iron core their physical

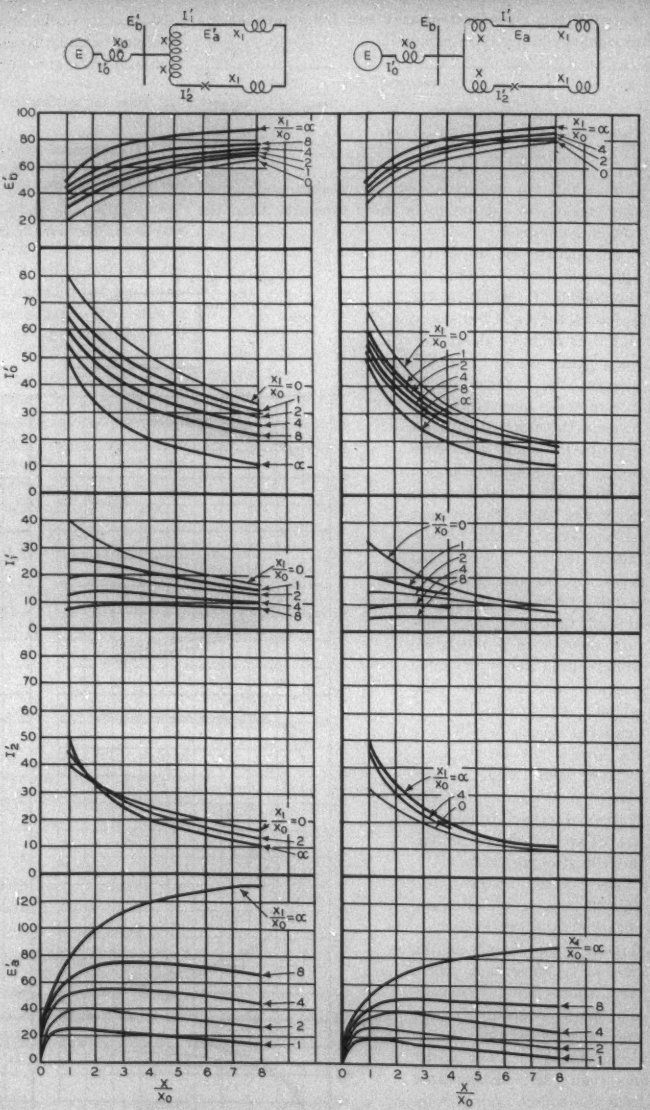


Figure 3. Comparison between split reactors and conventional reactors for feeder circuits. Feeders connected to same substation

size, and therefore their equivalent rating is based on the normal operation. Their rating would, therefore, be 3,000 kva. Since reactor kilovolt-amperes cost much less than transformer kilovolt-amperes, it is clear that a saturable-core reactor costs many times more than an air-core reactor. It is, of course, true that the circuit breaker used with a saturable-core reactor would cost much less than that used with an air-core reactor, due to the reduced short-circuit current. The reduction in circuit-breaker cost has not in the past been commensurate with the increased cost of saturable-core reactors, and for this reason they have not found a field of application as current-limiting reactors.

C. The Split-Circuit Reactors

The split-circuit reactor consists of two reactors placed so closely together that the reactance of one (due to mutual reactance) is affected by the current in the other. When used as current-limiting reactors they are connected so that with normal current in each reactor, their reactance is less than with current in only one. It is expected that under short circuit the current in the reactor connected to the fault will be very much greater than that in the other and, as a result, the reactance will be substantially greater at short circuit than at normal operation.

In some cases the current in the reactor not connected to the fault may be reversed in direction due to the fault, resulting in making the reactance of each reactor greater than if operating alone.

The reactors are usually wound as one continuous coil with a terminal brought out from the middle of the winding. The normal current is brought from the source of power to the middle terminal and divides, and part goes to each end terminal.

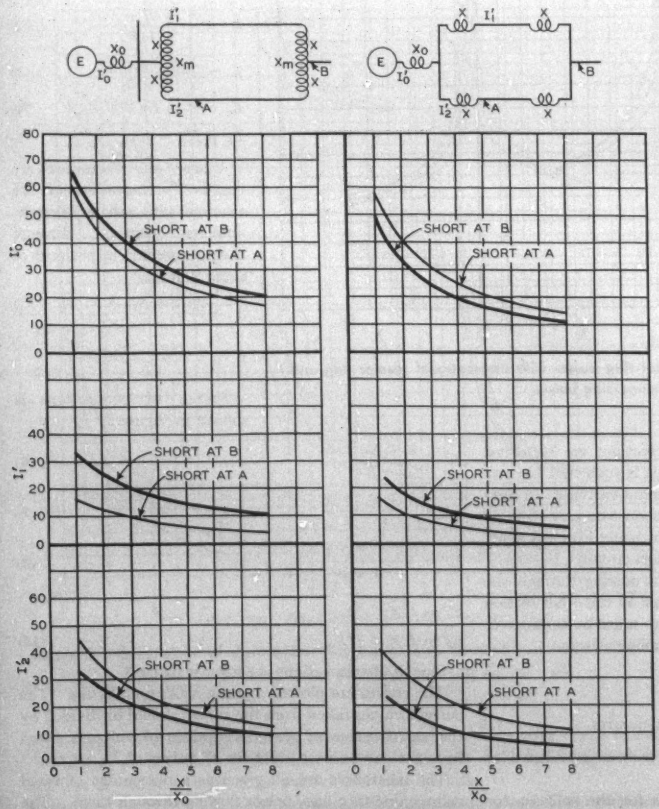


Figure 4. Comparison between split reactors and conventional reactors for feeder circuits. Feeders connected to same substation and reactors identical at each end

In the case of feeder reactors, it would be very desirable to separate the two coils from each other so as to fully insulate one from the other. This would permit placing a circuit breaker between the reactor and the bus. This, however, very materially reduces the mutual reactance and does not appear to be economically feasible in the dry type reactors, but could be done in a liquid-insulated reactor where the insulating distances are so much less.

In the dry-type reactors 50 per cent mutual reactance is about as high as is practical, while in the liquid-filled reactor the mutual may be somewhat higher.

The reactive drop across one section (one reactor) is equal to the current in that section times its reactance, plus the current in the other section, times the mutual reactance. The mutual adds, if the direction of the current in one section is positive compared to the current in the other section, and subtracts if negative. With the mutual reactance 50 per cent of the self-reactance, the resulting reactance of a section is 50 per cent with equal opposing currents, and 150 per cent with equal boosting currents.

With both sections carrying opposing currents, the

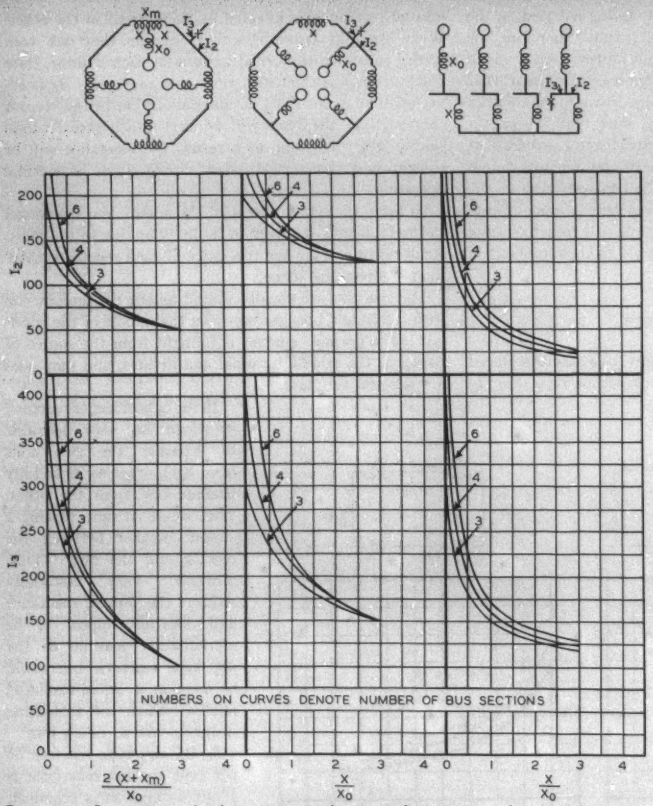


Figure 5. Comparison of split-reactor ring busses with conventional reactor ring and synchronizing busses

magnetic forces between the two sections are repulsive, and may be very great if the circuit is such that the two sections can carry opposing short-circuit currents. Therefore, in general, split circuit reactors must be very strongly tied together to prevent them from being expelled apart by the magnetic force incident to short circuit.

Due to mutual reactance, current passing through one section causes reactive rise in voltage on the other section which may be serious, and therefore must be considered.

There are two general cases for split reactors:

1. For feeder circuits.
2. For bus sectionalizing.

1. Split Reactors for Feeder Circuits

Three general feeder circuits have been considered as is shown in figures 2, 3, and 4.

The values given by the curves for the split-reactor feeder have been calculated from the formulas given below. These formulas are simple algebraic expressions, and the insertion of their proofs here is not considered warranted. The calculation of the curves for the conventional feeder reactors made use of standard formulas and are not given.

The value of mutual reactance used in all these calculations was 50 per cent.

The formulas 1 to 5, inclusive were used in calculations for split reactor feeders in figure 2.

Calculations for the split-reactor feeders shown in figures 3 and 4 made use of formulas 6 to 10, inclusive.

$$I_1 = \frac{X_m - X_0}{A + B} \tag{1}$$

$$I_2 = \frac{X + X_1 + X_0}{A + B} \tag{2}$$

$$I_0 = \frac{X + X_m + X_1}{A + B} \tag{3}$$

$$E_a = (I_3 - I_1)(X + X_m) \tag{4}$$

$$E_b = I_3X - I_1X_m \tag{5}$$

Where all reactances are reactive voltages across the reactors with a base kilovolt-amperes passing through them expressed in per cent of rated voltage.

$$A = \frac{X(X + X_1) + X_0(2X + X_1)}{100}$$

$$B = \frac{X_m(2X_0 - X_m)}{100}$$

Sketch of connections is shown in figure 2.

$$I_1' = \frac{X + X_m}{A + B} \tag{6}$$

$$I_2' = \frac{X + X_m + X_1}{A + B} \tag{7}$$

$$I_0' = \frac{2(X + X_m) + X_1}{A + B} \tag{8}$$

$$E_a' = I_1'X_1 \tag{9}$$

$$E_b' = I_3'X - I_1'X_m \tag{10}$$

Sketch of connections is shown in figure 3.

The curves are plotted against X/X_0 and X_1/X_0. The current values taken from the curves should be divided by the actual value of X_0. The values of voltages taken from the curves are correct for all values of X_0.

The reactances are all given as a percentage of rated voltage due to a base power flowing through them. The currents are given as the number of times the current of the base power can be divided into them.

An examination of these curves shows that the amount of feeder reactance (X) must in general be greater for the split reactor than for the conventional reactor; however, with equal currents in both sections, the effective reactance is equal to the self-reactance minus the mutual reactance, and since the mutual is 50 per cent, the effective reactance is only half of the self-reactance. This is considerably less than that required by the conventional reactors to limit the fault currents to the same values.

The mutual reactance helps to balance the load in parallel feeders due to raising the voltage on the underloaded feeder and lowering it on the overloaded one.

Whether or not there is sufficient merit in the split reactors to warrant their use in particular feeder circuits depends on the individual characteristics of the system and on the value that can be ascribed to reduced regulation in the particular system.

With these factors known, the curves make a rapid comparison possible. The circuits shown in figure 4 are particularly favorable to split reactors.

The case of split reactors for feeders may be stated as follows:

The advantage of lower regulation and better division of load between the parallel feeders must adequately balance the following disadvantages:

1. Higher cost due to a larger reactor and to the additional expense of supporting it to resist high repulsive forces.
2. Rise in voltage (E_a) which may be appreciable, as is shown in figure 2, if feeder reactance (X_1) is high.
3. The necessity of using liquid-filled reactors if circuit breakers must be placed in the individual feeders between the reactors and the bus.

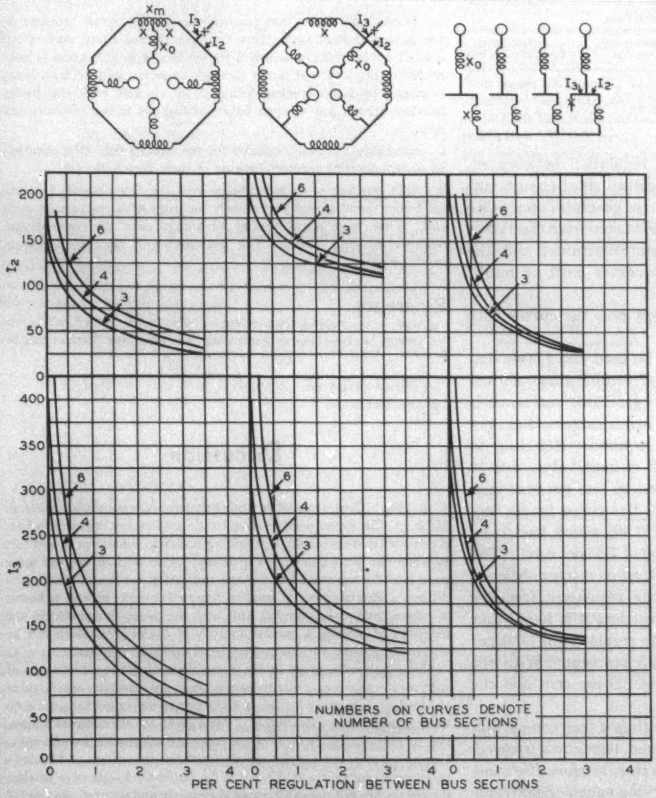


Figure 6. Comparison of split-reactor ring busses with conventional reactor ring and synchronizing busses based upon $X_0 = 1$ and $X_m = {}^1/_2X$

2. Split Reactors for Bus Sectionalizing

In order to ascertain if the split reactor has any value for bus sectionalizing, its use in ring busses has been compared with conventional reactors in ring and synchronizing busses. The split reactor is not suitable for use in synchronizing busses.

In figure 5 the ratio of bus reactance to generator reactance is plotted against short-circuit currents for the split-reactor-ring bus, the conventional ring bus, and the conventional synchronizing bus. Three, four, and six bus sections are included. The curves are based upon one per cent generator reactance. In practical cases the generator reactance is of course always greater than one per cent, and the correct short-circuit current is obtained by dividing the current values taken from the curves by the generator reactance. The split-reactor curves are based on $X_m = {}^1/_2X$.

In figure 6 short-circuit currents are plotted against the regulation due to load transfer. The calculation of the regulation is based on the following conditions:

1. That the kilovolt-ampere supply connected to each bus section is equal.
2. That the kilovolt-amperes transferred to one bus section from

all the other bus sections is equal to the kilovolt-ampere supply connected to one bus section. This means that the load on one bus section is equal to the kilovolt-amperes connected to two bus sections.

3. That these bus sections each contribute an equal amount of the transferred kilovolt-amperes.

4. The regulation is the reactive drop between extreme bus sections due to the load transferred.

5. That the reactance is the per cent of normal voltage across the reactance with the kilovolt-amperes of one bus section passing through it.

The formulas for the calculation of the regulation are given below:

Number of Bus Sections	Regulation Drop		
	Split-Reactor Bus	Conventional Ring Bus	Conventional Synchronizing Bus
3	$X + X_m$	$0.5X$	$1.5X$
4	$1.33\ (X + X_m)$	$0.667X$	$1.33X$
6	$1.80\ (X + X_m)$	$0.9X$	$1.2X$

In the curves in figure 6 the regulation between extreme bus sections is plotted against short-circuit current. The curves are based on a generator reactance of one per cent. The current values taken from the curves must be divided by the generator reactance, and the regulation values taken from the curves must be multiplied by the generator reactance.

The following examples will show how the curves may be used.

Suppose a six-section bus is to be used and I_2 (see diagrams in figure 6) is to be limited to nine times normal current of one generator and the generator reactance is 15 per cent. The regulation between extreme bus sections and the bus reactance is required. Referring to figure 6 and entering curves with current value of $9 \times 15 = 135$ (because curves are based on one per cent generator reactance), the split-reactor bus curve for six sections gives a regulation value of 0.49, which has to be multiplied by 15, giving a regulation of 7.35 per cent. The through reactance, $2(X + X_m)$, of the bus reactor obtained from the regulation by use of the regulation formulas is 8.18 per cent. By the same procedure it is found that with the conventional ring bus the regulation is 30.0 per cent and the bus reactance is 33.3 per cent. With the synchronizing bus the regulation is 9.0 per cent and the bus reactance is 7.5 per cent.

It should be noted that figure 6 gives a true comparison of relative short-circuit currents and regulation irrespective of the reactance of the generator, because the same reductions have to be made for varying values of generator reactance for all three bus schemes.

Since the reactance of generators will always be larger than the mutual reactance of the split reactor, the bus voltage will not rise above normal.

Figure 6 shows that the split-reactor bus has a marked advantage over the conventional ring bus. A comparison with the synchronizing bus is much more difficult because the two schemes are quite different. In addition to the currents shown on the curves, consideration must be taken of the short-circuit currents on the synchronizing bus itself, as these currents are very large. In many cases, bus reactance sufficiently high to limit fault currents on the synchronizing bus to safe values may make the regulation so high that the synchronizing bus scheme is difficult to operate.

The author realizes that the choice between these schemes depends a great deal on the individual conditions of particular stations, and has given these curves to assist in making the choice. The curves indicate that the split reactor bus should be given thoughtful consideration.

Summarizing

1. It has been shown that reactors shunted by circuit breakers do not have a general application. A very careful study may reveal limited applications in which a feeder bus of a substation is connected to the source of power through a reactor shunted by a large breaker, the large breaker being so interlocked with the feeder breakers that it has to open before any of the feeder breakers can open.

2. Saturable-core reactors have not yet found a field of application as current-limiting reactors because of their very high cost.

3. Split reactors show advantages over the conventional reactors for feeder circuits, and particularly for lines with reactors on each end. They have a substantial advantage over the conventional reactors for ring busses. The possibilities of their use warrants careful study.

Reference

1. THEORY OF D-C EXCITED IRON CORE REACTORS AND REGULATORS, A. Boyajian. AIEE TRANSACTIONS, volume 43, 1924.

Discussion

J. A. Elzi (Commonwealth and Southern Corporation, Jackson, Mich.): This paper is interesting to the application engineer in that it deals with the problem of providing sufficient reactance in a circuit to limit the fault current to a desired value without at the same time introducing excessive voltage regulation for normal load conditions. The engineer is usually tempted to try various schemes of connections to accomplish this, and the paper demonstrates the necessity of making a careful analysis of the results which can be obtained by using various reactor connections and designs.

The conclusions given in the paper regarding the advantages of split reactors for feeder circuits where there are reactors at each end of the feeders seem quite logical, but the curves presented in figure 4 do not appear to demonstrate this. For a given set of reactance values, the currents I_0', I_1', and I_3' apparently are all greater for the split-reactor scheme than for the conventional-reactor scheme. This is to be expected for faults at B but not for faults at A. It may be that the curves are not being interpreted properly and an example similar to that presented for the six-section bus of figure 6 would be helpful in clearing up this point.

S. I. Oesterreicher (Metropolitan Device Corporation, Brooklyn, N. Y.): Due to first cost, complications in circuit arrangement and control in scheme B, as well as greater space requirements for scheme A, there are, no doubt, good reasons from the operating standpoint for objecting to these two schemes as described in Mr. Kierstead's paper.

However, the tee-circuit reactor—also known by the names of split- or twin-circuit, double or bifurcated reactor, has certain operat-

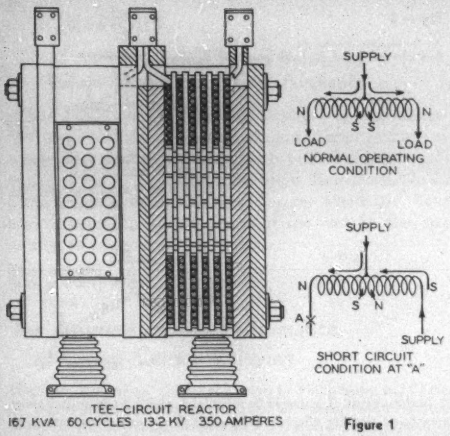


Figure 1

ing characteristics for which it should in the future receive greater popularity than during the past.

Much of the distrust toward the tee-circuit reactor is due, no doubt, to some shortcomings of early designs. After correction, it functioned in accordance with the intent of its inherent characteristics. Some of these later tee-circuit reactors have over 12 years of satisfactory operating record to their credit.

As stated by Mr. Kierstead, the advantage of this type of reactor is that during normal operation the voltage drop across the reactor is

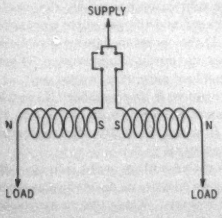


Figure 2. Tee reactor for two independent circuits

reduced by the amount of mutual inductance between the two windings. During short circuits the subtractive mutual inductance becomes additive, and thus the reactance through each coil half increases and there is automatically a greater amount of short-circuit protection inserted into the respective circuit.

Unless there is a simultaneous short circuit in both load legs of the reactor, the reactance value through the reactor will always be greater during short circuits than during normal operation. This is true even when one of the two circuits is open beyond one of the reactor load side terminals.

While simultaneous short circuits in both reactor legs are exceptions from normal rule, nevertheless, the reactor has to be designed for just such emergencies. The repelling forces between the two halves during such short circuits, especially with such high mutual inductance values as Mr. Kierstead assumed in his calculations, may reach well into hundreds of thousands of pounds. I presume this value was assumed to illustrate the advantages of the *T* reactor to its fullest extent. The mutual inductance in our coils was limited close to 30 per cent.

I believe the *T* reactor would have its greatest field of application on secondary distribution feeders up to the five-kv range. In these circuits as little as possible reactance would be most welcome from the standpoint of regulation. With increase in generating capacity and load, the usually inexpensive breakers on these circuits would require greater protection during shorts, which could be readily provided by the *T* reactor. The reactor being compact, takes less space, is lighter, and does not cost more than two single-phase coils. To eliminate the disadvantage of having two circuits out of service at the same time in case of disturbance on only one side of the *T* reactor, the two feeder circuit breakers may be placed upon the supply side of the circuit beyond the common terminal of the reactor. Beside the regular equipment of the two feeders this arrangement would require only one additional terminal upon the reactor.

P. N. Sandstrom and **E. L. Michelson** (Commonwealth Edison Company, Chicago, Ill.): This paper presents interesting data regarding the application of the split reactor on feeder circuits and for bus sectionalizing. Some time ago, it was proposed by the Commonwealth Edison Company to use the split reactor in a somewhat different manner, shown in figure 3*a* of this discussion. In this diagram, busses 1 and 2 represent the main busses in a large station; these busses are normally separated, but the split reactor can be used to connect a source of power to feed both busses simultaneously, and at the same time maintain a certain degree of separation between the two busses. In this way, it possible to obtain a low value of reactance between the source and the load, and yet have a high value of reactance between the two main busses in the station. It is recognized that this application is a special form of the feeder circuit described in the paper.

Figures 3*c* and 3*d* of the discussion show values of fault current corresponding to I_3 of figure 2 in the paper, for values of x/x_0 from 0

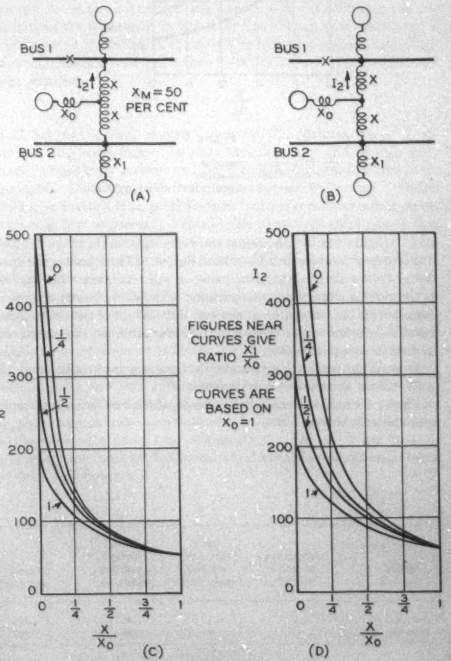
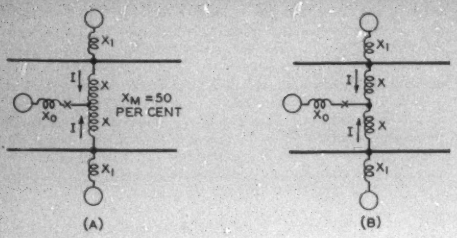


Figure 3

A—Split-reactor connection
B—Conventional design
C—Short-circuit currents with split reactor
D—Short-circuit currents with conventional reactor



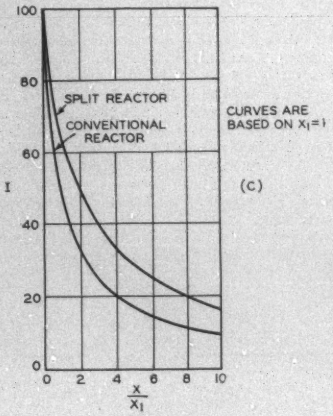


Figure 4

A—Split-reactor connection
B—Conventional connection
C—Short-circuit currents for faults shown in *A* and *B*

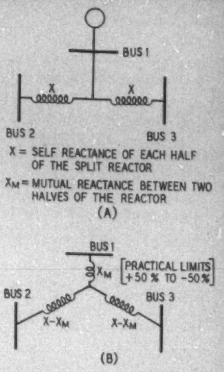
to 1. Figure 4 of the discussion shows the fault currents for faults in the source of power which feeds both busses. These curves in figures 3 and 4 show that for the same value of self-reactance, the split reactor gives a more effective separation between the busses than is obtained with the conventional reactor, but the use of the split reactor results in higher values of fault currents for faults on the source connected to the split reactor.

It would be interesting to know the comparative cost between the split reactor and the conventional reactor.

Figure 5 shows the equivalent circuit which can be used to represent the split reactor.

Figure 5

A—Split-reactor connections
B—Equivalent circuit for split reactor



In this circuit, X_M should be taken as positive if the mutual reactance has a positive effect; that is, if fault current in one circuit results in a drop in voltage on the second circuit. X_M should be taken as negative if the mutual reactance has a negative effect; that is, if fault current in one circuit results in a rise in voltage on the second circuit. This is in accordance with the accepted method for dealing with such circuits. It will be noted that this is contrary to the method used in this paper and in figures 3 and 4 of the discussion, since a negative mutual effect has been expressed as a positive quantity.

F. H. Kierstead: In accordance with Mr. J. A. Elzi's request, I wish to give an example covering a comparison of the split reactor with the standard reactor. In the split reactor assuming the reactance of one section (X) is four per cent and the generator reactance X_0 is one per cent, and a fault at A, the curves in figure 4 give I_0 = 21.5, I_1 = 7.5, and I_0 = 28. Since the mutual inductance is 50 per cent, the reactance to rated balanced load current is two per cent.

Referring now to the standard reactor, if its reactance (X) is 3.5 per cent and the generator reactance is one per cent and a fault at A, curves in figure 4 give I = 21.5, I_1 = 6.5, I_0 = 27. Reactance to rated balanced load current is 3.5 per cent.

Figure 3 of this discussion shows the advantage of the split type of reactor for a fault on bus 1, while figure 4 shows its disadvantage with a fault on the midpoint of the split reactor. These two curves show that the split reactor must be properly applied to obtain its benefits.

Mr. Oesterreicher shows practical applications of the split-type reactor. In the split-type reactor for independent circuits care must be taken that the two sections are insulated from each other for the full voltage, and if one of the circuits is taken out of service to be worked on, it must be grounded at both ends so that the mutual inductance does not induce serious voltages in the idle reactor.

Discussions

of AIEE Technical Papers Published Before Discussions Were Available

ON THIS and the following 13 pages appear discussions submitted for publication, and approved by the technical committees, on previously published papers presented at the AIEE winter convention, New York, N. Y., January 24–28, 1938. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

The Application and Performance of Carrier-Current Relaying

Discussion and authors' closure of a paper by Philip Sporn and Charles A. Muller published on pages 118–24 of this volume (March section), and presented for oral discussion at the relays and reactors session of the winter convention, New York, N. Y., January 25, 1938.

T. G. LeClair: For discussion see page 291.

R. M. Smith (Westinghouse Electric and Manufacturing Company, Newark, N. J.): While the paper by Messrs. Sporn and Muller deals primarily with the problems to be solved by the application of carrier-current relaying, we believe that some comments on the particular scheme of carrier relaying are worth while.

In reviewing the steps in the development of carrier relaying toward faster operation it is apparent that one outstanding contribution assisted in the realization of speeds in the order of one cycle. This improvement consisted in the use of a normally blocked trip circuit by the means of a receiver relay whose tripping contacts are normally open. This method of handling the carrier-operated blocking function was first used by the authors of the paper and I believe that due credit should be given them for this contribution to the development of carrier-current relaying.

One thing to be noted in the one-cycle scheme described is that the speed of clearing faults has been gained at the expense of reliability in blocking on external faults. This comes about, of course, from the use of circuit-opening contacts to remove carrier rather than circuit-closing contacts. This means that on quick reversals of power which occur on parallel lines and loop systems, carrier is stopped by a circuit-opening contact and established at the opposite end of the line by a circuit-closing contact. The opening contact will ordinarily beat the closing contact and there will be a short interval in which no blocking signal is present. The authors have circumvented this difficulty by the use of an additional temporary blocking relay. It is questioned whether this is good practice since an undesirable time delay will be introduced in clearing an internal fault which occurs immediately after an external fault. Would it not be preferable to slow up clearing times by, say, 0.25 to 0.5 cycle and use this much time interval as a definite margin of safety in blocking?

It is observed that the contacts which start carrier and the tripping contacts are on the same overcurrent element. This means that for external fault currents, which are near the minimum pick-up value of the relays, the relay at one end of the line may operate, while, due to different current-transformer characteristics, the relay at the other end may not operate. If the relay at the line end where power flows into the bus is the one which does not pick up, then a blocking signal is not sent to prevent unnecessary tripping at the other end. The obvious thing to do is to set both relays the same and considerably below the minimum fault current expected. On phase-to-phase faults it is generally not difficult to do this, but on ground faults where fault resistance or distance may limit the current to very low values, it may be very difficult to set the relay pick-up value below the lowest possible fault current. One solution of this trouble is to place the carrier start and tripping contacts on separate elements. The starter element can then be set considerably below the tripping element, thus assuring that whenever the currents for external faults approach the minimum pick-up value of the tripping element, they will be safely above the pick-up value of the carrier start element.

Since a three-phase directional element requires that the ground fault current be twice the magnitude of the load current, to indicate fault power correctly, there is grave possibility that the relay scheme, as described, will fail to clear internal ground faults involving low currents. Of course, this characteristic of the three-phase directional element has been encountered before on conventional relaying, but its seriousness in a carrier scheme is much aggravated because the failure of only one directional element to function will block both ends from tripping. We feel that single-phase directional elements for phase, and a separate ground directional element, are much more desirable in a carrier scheme. It may be argued that the single-phase element is liable to go wrong on a system with a multiplicity of ground points, or due to load currents, but this is taken care of by supervising the directional element through an impedance element and the use of a ground preference scheme as described in the paper by Harder, Lenehan, and Goldsborough, whereby on ground faults the ground relays can take command of the situation from the phase relays.

Messrs. Sporn and Muller have cited several of the advantages in the application of carrier relaying and have described actual examples of the applications which have served to bring out the specific features to be gained by the use of carrier relaying. The record of their experiences with this type of protection should be of great interest to system-protection engineers, as it demonstrates the reliability of the equipment in actual service. They have stimulated a great interest in this form of protection and their paper shows that from an operating standpoint their faith in this type of protection has been justified.

O. C. Traver (General Electric Company, Philadelphia, Pa.): I appreciate the frank exposition that Messrs. Sporn and Muller have made of both their sorrows and their joys in connection with a commendable pioneering work with carrier-current protection. To me the major interest is in table I where much more information exists than is at first apparent. I should like to analyze these figures in a search for the reason back of the authors' boundless faith indicated by their remarks at the end of section II concerning eventual "perfect performance."

In this review I will offer no alibi and only cold figures will be used, directly from table I without modification. I understand from the text that the heading "Operations on Internal Faults" might be more properly expressed as "Number of Internal Faults." As these were invariably cleared correctly, we can say that there were at least two correct breaker operations for each fault. I am therefore going to double all quantities given under that heading so as to approximate the number of correct operations for direct comparison with those that are incorrect. On the other hand, I will ignore the recorded 2,000 possible chances for operation as being of debatable concern.

Year Installed	Total Correct Breaker Operations	Total Incorrect Breaker Operations	Approximate Years in Service	Ratio Correct
1936	18	1	2	95 per cent
1937	12	0	½	100 per cent

Observe that the over-all ratio definitely and consistently *improves* with years of service, indicating that troubles with a given equipment are rapidly eliminated.

The installations of the last two years have not been in action long enough to show a trend.

But there is real comfort here again because it indicates that later days relays have been designed for this work, and we can now confidently expect to start from a higher plane at the very outset, and with the vision of such a prospect perhaps the authors are justified in looking forward to results which in comparison with their pre-carrier experience might not be improperly considered as "perfect performance."

The authors have told of having corrected certain troubles. Let us see what actual effect followed. We will admit that one may expect diffculties the first year or so, and then check results after these have had a chance to be ironed out. For example, the operating record for the years 1935, 1936, and 1937 for all relays installed in 1933 shows at least 74 correct operations and one incorrect. This gives 98.6 per cent correct operations, and for the speed involved that looks excellent. Even better is the entire record for 1937 with 96 correct and one faulty operation giving 99 per cent correct. But we won't confine ourselves to scattered illustrations. Maybe I just looked for good ones, so how about the rest of the figures?

If troubles met in the field are truly eliminated in the earlier years, there should be progressive improvement in equipments that have been installed for longer periods. Yearly variations are apt to be irregular and confusing. Accordingly let us lump together, for example, all the operations for the years from 1933 to 1937 of just those relays installed in 1933 and then similarly for each succeeding year and so examine all the figures broken down in groups based on the year of installation.

Year Installed	Total Correct Breaker Operations	Total Incorrect Breaker Operations	Approximate Years in Service	Ratio Correct
1933	174	5	5	97 per cent
1934	170	17	4	91 per cent
1935	32	4	3	89 per cent

E. E. George (Tennessee Electric Power Company, Chattanooga): All relay engineers realize that there have been great improvements in carrier current protection in the last few years. The present paper is therefore very welcome at this time—particularly because it includes a schematic and circuit description of the latest practice. The detailed operating record given is also of interest to both manufacturers engineers and operating engineers.

Experience with a recent installation of carrier-current relay protection indicates that the total cost per terminal is now between $4,000 and $4,500 installed, depending upon the type of backup protection, if any. Taking the lower figure of $4,000 and applying the percentage of overheads commonly used by utilities for major equipment, one gets a total carrying and operating charge of something over $40 per terminal per month, which means that on the above basis the cost of carrier protection would pay for 20 to 30 miles of pilot wire between two terminals. This figure should be reduced slightly on account of the cost of the simpler pilot wire relays. However, it is obviously improper to apply the same percentage of depreciation, obsolescence, and maintenance to carrier-current equipment and relay equipment that is applied to power houses and transmission lines, so we may say that the figure derived above is too small. As another approach to the subject let us take the carrying and operating charges generally applied by communication companies to relay, switchboard and carrier equipment which works out to be about 30 per cent per annum—and this is admittedly insufficient on special equipment requiring particularly skilled maintenance. On such as basis this would give an operating and carrying charge of $100 per month per terminal, which would lease 25 miles of toll circuit per terminal or 50 miles of circuit between two terminals. Experiments are now being made to determine the utility of ground return or composite telegraph circuits (which takes a considerably lower rental for pilot wire purposes).

It is thus apparent that the length of the transmission circuit to be protected is a primary factor in determining the economic feasibility of carrier-current protection as compared with other methods. Among other factors are the availability of existing coupling equipment for carrier-current dispatching communication, the existence of trained personnel familiar with electronic maintenance, and the availability of high-grade communication channels between the power terminals, etc.

The industry owes much to the development of equipment and methods carried on by Mr. Sporn and his associates. While any endeavor to advance the art and science of electrical transmission may frequently subordinate economics during the development period, sooner or later economic considerations will determine how rapidly new developments are accepted into general practice. Any criticism of pilot wire relaying in a carrier relay paper invites such comparisons. Although the author of this discussion is just now making his first installation of carrier-current relay protection, his experience with pilot wire protection leads him to suggest that to the seven conclusions of Messrs. Sporn and Muller should be added the following:

8. Carrier-current relaying is now becoming the accepted standard on long transmission lines. On urban tie lines and short transmission lines (regardless of voltage) pilot-wire protection is more economical and is adequately reliable. On transmission circuits of intermediate length the decisions between the two types will depend upon many factors, such as existing dispatching communication practice, existing maintenance personnel, existing commercial communication channels, availability of new capital, and other considerations which are more largely economic than technical.

O. A. Browne (Western Massachusetts Companies, Turners Falls, Mass.): The paper presented by Mr. Sporn and Mr. Muller expresses a great deal of enthusiasm for the carrier-controlled relay which one can hardly appreciate unless one has had experience with it. Our system has had these relays in service at 26 line terminals since spring of 1933, and although some troubles have been encountered similar to those mentioned in the paper, they have all been fairly easily corrected and we are just as enthusiastic as the authors.

Our relays are all of the older four-cycle type used on line sections where either one or two tapped stations were involved. This, with other complications, made any type of overcurrent or distance type of relaying difficult to work out without cascading time and current settings to the point where lines were often burned off.

Since the installation of carrier equipment in four years we have had only one case of lines burned off during a lightning storm. Emergency line patrol and repair work on these lines during lightning storms has only averaged one case a year.

We found it desirable, as the authors did, to incorporate a time delay so that on the termination of a fault the receiver relay would not close the contacts blocking tripping until the ground and phase relays had a chance to open their contacts. We accomplished this by the installation of a capacitor in series with a resistor connected across the operating coil of the receiver relay. On the receipt of a carrier signal the capacitor is charged up. On termination of the signal the capacitor is discharged through the operating coil of the receiver relay, thus keeping it from resetting for four to five cycles. This seems to be a more positive method than the introduction of another relay with instantaneous opening and time delay closing, although it may not be applicable to the newer relays.

Reliability of tubes is borne out by our experience. In four years of operation, only one failure to block tripping could be attributed to a tube failure.

E. H. Bancker (General Electric Company, Schenectady, N. Y.): There is an intermediate stage in most developments after the principles have been outlined and the first installations made when people hesitate about adopting something new and look for the story of results secured by those who first dared to try it. The significance of this paper lies in the fact that it gives the results of several years' experience of an early user of many terminals of carrier relaying, a development that has been the subject of several previous papers, but all of which dealt with design features. Now we have the "proof of the pudding."

As a distinguished New Yorker was wont to say, "let's look at the record." First the adoption of carrier relaying was the only practical solution to certain operating problems. In other cases it was found to be the most economical solution. In still others it was the best, and even though something of lower cost might have served, the better performance expected from it was apparently thought worth its slightly higher cost. Thus, as was said of carrier relaying in its development stages, it has furnished the system designer and operator with a new tool of great utility. Secondly, it has come up to expectations in performance. As part III of the paper shows, the over-all accuracy on the comparison of correct and incorrect operations is not as good as might be desired although it compares favorably with other forms of high-speed relaying. The interesting and encouraging things are: (1) that the carrier system was called upon to function many times and the percentage failures were so small that the over-all performance was about as good as other relaying used for similar purposes; and (2) that every cause of a false operation was found and remedied so that the 1937 performance was better than could be expected of other forms of relaying. This indicates that while there may be growing pains, the adult is a healthy citizen.

Finally the carrier part of the equipment accounted for only half as many failures as were attributable to the relays. Certainly the relays cannot be said to be any more difficult to adjust and maintain than any others, and assuming what is probably true, that they were well maintained, it will be seen that the carrier part has an even better record of performance than relays. This means that the carrier equipment is even more dependable than relays, which should allay some of the doubts as to the reliability of a carrier pilot channel.

Naturally the results of experiences such as those cited in this paper are incorporated in the design as quickly as they are made known. Coupling-capacitor gaps are now enclosed in a housing at the base of the capacitor where they are protected against the weather. Line-trap capacitors are mica with no appreciable temperature error, and they are protected against damage from overvoltage by a distribution arrester having a characteristic that does protect even up to the highest traveling wave currents that may be expected.

In the modern schemes the contacts of the receiver relay are normally open and are mainatined so during an external fault so there is no race between them and the tripping relay after the fault has been cleared. Directional-relay contacts have been greatly improved by the addition of antibounce features. Moreover they normally close to stop carrier rather than open as in the authors' scheme where the additional tripping speed of a fraction of a cycle gained thereby was considered necessary. Directional relays themselves have much increased torque and speed with lower coil burdens as a result of the induction cylinder development.

The necessity for so many correct blocking operations has been greatly reduced by diminishing the area in which the occurrence of a fault causes an attempt to trip, through the use of distance relay elements.

With these many improvements, whose origin lay within actual experience such as is reported in this paper, results at least as good as those obtained in 1937 should be realized right from the start in any new installations.

A. F. Rose (American Telephone and Telegraph Company, New York, N. Y.): The first paragraph, in referring to the use of pilot wires for relaying, states: "Neither of the above schemes, however, has ever met with any great favor in the United States on account of the prohibitive cost of pilot-wire circuits, particularly on long lines, and because in the long run the scheme itself is no more reliable than the pilot wire. Experience has shown that the reliability of the latter is not quite at the 100 per cent level desired and mandatory for proper service." The authors apparently feel, therefore, that the carrier method is superior to the use of pilot wires. With respect to pilot wires leased from the telephone companies the following facts may be of interest. These facts relate both to relative costs and reliability.

With respect to costs, figures have been presented which indicate that the use of power-line carrier channels involves a first cost installed of about $4,000 more per terminal than the pilot-wire plan. The added annual expense for two terminals, including interest, insurance, administration, taxes, depreciation, and maintenance is probably not less than $2,500 (This figure is supposed to cover the allocated cost of all work, some of which might conceivably not add to "out of pocket" cost in an individual case but which would form part of an engineering comparison) which would seem to indicate that, in general, the use of leased channels would be economical up to 75 to 150 miles. The capital outlay and risk of obsolescence with the carrier scheme would thereby be avoided as would also the necessity of specially trained personnel for maintaining the equipment.

With regard to reliability, figures are presented in the latter part of the paper pertaining to the performance of a number of carrier systems over a period of several years. These figures show that out of about 2,000 occasions when called upon to transmit a signal, the carrier channels failed to function in 27 instances, only nine of which are, however, attributable to failure of the actual carrier channel. Converting the authors' figures to a percentage basis, which eliminates any need for consideration of the number of systems or years of service, we find that the carrier channels were out of service one-half per cent of the time, or putting it in another way, each circuit was on the average out of service about 1.5 days per year. Extensive summaries of failures on commercial telegraph channels, which should be representative of the type of channels which would be leased for pilot-wire relaying, indicate "out of service periods" of about an hour and a half per year. This is less than one-twentieth of the "out of service" time indicated for the power line carrier arrangement.

Philip Sporn and **C. A. Muller:** Referring to the statement of Mr. R. M. Smith that in the one-cycle system described by the authors the speed of clearing faults has been gained at the expense of reliability in blocking on external faults: Our opinion is that this is not true but, on the contrary, the scheme described is more reliable than the scheme employing circuit-closing contacts to stop transmission of carrier. It is evident that in the scheme described by the authors the employment of the auxiliary lockout relay prevents any false tripping from occurring on external faults due to quick reversals of power which occur on parallel lines and loop systems. On the other hand, in the scheme employing curcuit-closing contacts to stop transmission of carrier, the prevention of false tripping on external faults due to sudden power reversals is based on the premise that the directional relay contacts at one end of the line will open before the corresponding contacts at the other end of the line will close. It is the authors' opinion that under certain conditions the circuit-closing contacts may close before the circuit-opening contacts open, in which case false tripping would occur on external faults. The reason for this is that the relay whose function is to close its contacts on sudden reversal of power, has a much higher voltage applied to its potential coils than the directional relay whose function is to open its contacts. This is very apt to happen if the contact spacing of the directional relays is so adjusted as to obatin a maximum relay time of one cycle for the clearing of all types of internal faults.

In regard to Mr. Smith's comment of the auxiliary lockout relay introducing an undesirable time delay in clearing an internal fault which occurs immediately after an external fault, we wish to point out that it has been the authors' experience that this occurs very infrequently. However, when it does happen this extra time delay will amount to approximately three to four cycles, which is not considered very serious due to it occurring so seldom. Moreover, the employment of this auxiliary lockout relay gives out of step protection to the scheme without the addition of a complicated relay arrangement usually recommended for out-of-step protection on carrier current relay systems when such protection is desired.

The question of employing one set or two sets of fault detector relays, referred to by Mr. Smith, to prevent the possibility of incorrect tripping on external faults when the fault currents are near the

minimum pickup value of the relays was thoroughly studied by the authors, and it was their conclusion that only one set of fault detector relays was necessary; the adoption of this obviously results in a simplified relay scheme. For phase protection it will be noted that the impedance-type fault detectors are employed. In case of an external fault, the fault detector at the line end where power flows into the bus bars has a lower voltage applied to its potential coil than the fault detector at the opposite end of the line has applied to its potential coil. Hence, this fault detector will have a lower current pickup than the fault detector at the other end of the line. However, this same fault detector starts transmission of carrier, blocking tripping action at both terminals of the line. Therefore, for phase-to-phase external faults no incorrect tripping should occur. For external ground faults, there is a possibility of incorrect tripping occurring when the ground currents are near pickup value of the ground fault detectors due to inaccuracies of current transformer ratios. However, the authors' experience up to the present time has not indicated an incorrect operation from this cause, thereby proving the infrequent occurrence of this condition. If future experience should show this to be serious, we expect to employ two ground fault detectors.

The authors believe the employment of a three-phase power directional relay is more satisfactory than the use of three single-phase power directional relays described by Mr. Smith. Our experience has been that a three-phase power directional relay is more reliable in its operation for phase-to-phase faults near the station bus bars. When applied to carrier-current relaying a much simpler relay arrangement is obtained than by the use of three single-phase power directional relays in conjunction with a ground directional relay. The type-*CBP* relay illustrated in the paper having only three phase elements is only applied when the minimum ground currents are far in excess of maximum load currents. In other words, it is only applied on the line section where ground-directional relays are not necessary. On line sections where ground-directional relays are necessary, the type-*CCP* three-phase directional relay is applied having three phase elements and a ground element operating on the same shaft. In this relay the ground element is made very sensitive and no difficulty is experienced with overcoming the torques produced by load currents. Furthermore, the employment of the type-*CCP* eliminates the use of a ground preference scheme, thereby simplifying the relay arrangement.

Finally, after carefully comparing the relay arrangement described by the authors with that described in the paper by Harder, Lenehan, and Goldsborough, referred to by Mr. Smith, the authors are of the opinion that the scheme they describe is a more simplified arrangement requiring less maintenance and having less likelihood of false operation. To an operating man the scheme described in the paper by Harder, Lenehan, and Goldsborough appears to be a Christmas tree setup with relays in profusion acting as the decorating medium.

Messrs. Rose and George both raise the question of the relative costs of carrier-current channels versus leased pilot wires from the telephone companies. The following figures may be of interest: The first cost for the system employing carrier-current channel is approximately $4,000 per terminal, which includes the cost of protective-relay equipment. Of this amount $2,400 represents the installation cost of carrier-current channel per terminal, and $1,600 represents the installation cost of the protective-relay equipment. The annual carrying charges, including interest, taxes, depreciation, and maintenance, for the carrier-current channel would be approximately $1,000 for two terminals. This represents a fixed and maintenance charge of over 20 per cent. Assuming a rental for leased pilot wires of $50 per mile per year for two conductors, then it is evident that the use of leased channels will be economical up to twenty miles instead of 75 to 150 miles as stated by Mr. Rose.

With regard to reliability of operation of carrier-current channels versus leased pilot wires, the following analysis may be of interest: The operating record of carrier-current relaying given in the paper covers 16 line sections which have been in service for an average time of 3.3 years. In other words, the operating experience given in the paper covers 53 line-section years. During this period only nine incorrect operations occurred due to the failure of the actual carrier channel. Extensive summaries of failures on commercial telegraph channels, which should be representative of the type of channel which would be leased for pilot-wire relaying, indicate "out of service periods" of about an hour and a half per line-section year. Then for the period covered by the operating experience in the paper, namely, 53 line-section years, the total outage period would amount to 79 hours. We believe that at least half of this outage period would occur during severe lightning and sleet storms just at the time that faults occur on transmission lines. The authors believe, and operating engineers in general will agree, that with the leased pilot-wire channel out of service 40 hours during severe lightning and sleet storms, that more than nine cases of trouble could be expected on the transmission system during that distress interval. There would of necessity, have to result more than nine incorrect relay operations chargeable to the leased pilot wire channel. It needs to be kept in mind, too, that all of the incorrect operations due to failure of the carrier channel occurred in the first two years of carrier-current experience, and that during the remaining two and a half years of carrier-current operation experience no incorrect operation occurred due to the failure of the carrier channel. Furthermore, these nine failures were all attributable to faulty design which has since been corrected, and no further failures from these sources are to be expected in the future. This has been abundantly demonstrated by the last two and a half years' operation, which was 100 per cent correct in so far as the carrier channel is concerned.

The authors are very gratified to find that the experience of Mr. Browne, both as regards to benefit obtained from carrier relaying and as to reliability of component parts of the equipment, has been the same as theirs.

Mr. Bancker's analyses of the cause of the original mild difficulties with carrier are interesting, and, the authors believe, to the point. They very definitely cannot quarrel with the conclusion reached by him, since they believe their experience definitely bears this out, and that results at least as good as those obtained on their system in 1937 can be realized in any new and modern carrier installation. The same thing holds true with regard to the discussion of Mr. Traver. The authors believe with him that the results that are being obtained with carrier today are something that neither they nor any other practicing relay engineer of a decade ago even dared to envision, and the results that are obtainable today with carrier are as close to perfect performance as there is a call for in a system aiming to give the very highest type of service. Carrier relaying very definitely has reached the point where its performance, given proper application engineering, can be predicted with the utmost certainty. That performance is in general so much of an improvement over anything that can be obtained by any other single relay scheme, that there does not appear to be any doubt that as its performance and functioning becomes better known, its use is bound to spread more and more widely.

A System Out of Step and Its Relay Requirements

Discussion of a paper by Leslie N. Crichton published on pages 1261–7 of volume 56, 1937, AIEE TRANSACTIONS (October 1937 issue of ELECTRICAL ENGINEERING) and presented for oral discussion at the relays and reactors session of the winter convention, New York, N. Y., January 25, 1938.

E. H. Bancker (General Electric Company, Schenectady, N. Y.): Man's easiest way of learning seems to be through much repetition. Not many of us have frequent occasion to study loss of synchronism and yet it has an important effect upon the action of many types of relays. Therefore, although the information presented in this paper is not new, it is given in a new and easily understood manner, and as it is knowledge we relay engineers need, it bears repetition. Perhaps if we read or hear it enough times we may be able better to interpret records of peculiar relay action or to determine in advance what may be expected to happen to some of our relays when systems swing or lose synchronism.

A little work has already been done in determining how loss of synchronism affects relays, especially the distance type. This indicated that there was some danger of sectionalizing at several points between the machines out of step, thereby leaving areas without a source of supply. Several solutions have been proposed, most of them including means for preventing distance relay action under the circumstances and requiring an out-of-step relay to separate at the most convenient point.

As the author says, most out-of-step relays must wait for three or four slip cycles to differentiate completely between loss of synchronism and every other condition of operation. This should usually be satisfactory, but it may be of interest to know that it is possible, if necessary, to construct an out-of-step relay that will operate during the first slip cycle and for no other condition except loss of synchronism.

This paper will have served its purpose if it merely helps a few of us to get a better mental picture of the quantities existing when machines go out of step. The simple, direct analysis is a big help in acquiring an understanding of this complicated phenomenon.

H. R. Paxson (Philadelphia Electric Company, Philadelphia, Pa.): In Mr. Crichton's paper the graphical method of treatment of the conditions at different points on a system running out-of-step enables the rather complex current and voltage relationships to be readily visualized. This method of representation would have been extremely useful to us early in 1935 when the problem was forcibly presented to us by a large frequency converter pulling out of step and continuing to run out of synchronism until considerable damage to the machine resulted.

Previous to this occurrence we believed that induction-type overcurrent relays would furnish protection against a condition of this kind. This belief was based on the fact that our smaller frequency converters equipped with induction type overcurrent relays had been clearing successfully during out of step conditions. Since the induction relays in the case of the large frequency converter did not perform as expected on the occasion in question, an analysis of the problem was made for the purpose of developing suitable out-of-step protection. As the action of induction relays was first investigated a few words on them is appropriate at this time.

The reset time of an induction relay on zero current is constant for any given lever setting while its operating time is a function of the current so that on a varying current such as results from a synchronous machine running out of step, the relay contacts will swing back and forth but will not actually close until the current swings become great enough for the relay disk to travel farther forward than backward on each swing. The time taken by the relay is therefore the time required for the disk to oscillate back and forth until the summation of the differential amounts of travel on each swing equals the total travel.

For a given setting the inverse time-current characteristics of induction relays makes the number of poles which may be slipped before tripping a function of several variables which include the maximum value of the current surges as a percentage of the relay tap setting and the speed with which the disk resets on currents below the tap setting. On the basis of using relay settings determined necessarily by the maximum load and the need for selectivity with other relays, it was found that if the generating capacity was high compared to the rating of the frequency converter, induction disk relays will eventually trip on out-of-step conditions but if the generating capacity should be low they may not trip at all. As three pairs of poles had been established as the maximum number which the protective relays should allow the frequency converters in question to slip, induction relays were obviously inadequate for this application.

Fortunately an oscillograph record was obtained. This showed that two pairs of poles were slipped during the first second after clearing the fault which initiated the disturbance and that the number of pairs of poles slipped, increased to seven per second at the end of the ninth second where the record stopped. With this background a study of out-of-step relay protection was undertaken. A method of analysis somewhat different from that presented by Mr. Crichton was followed but substantially the same conclusions were reached with respect to the requirements which the relays should meet in order to distinguish an out-of-step condition from hunting, overload swings, and faults elsewhere on the system.

Several relay designs were considered but at the conclusion of the study the out-of-step protective scheme described toward the end of Mr. Crichton's paper was chosen and installed on both the 25-cycle single-phase generators and 60-cycle three-phase motors of two 30,000-kw and three 15,000-kw frequency converters. The out-of-step relays consist of a duodirectional watt element whose contacts are in series with an overcurrent element. The two elements working together operate a notching train of auxiliary relays so that three complete power reversals accompanied by overcurrent are required to pick up all the relays in the notching train and close the tripping circuit; a timing device automatically resets the notching relays.

The overcurrent elements were set to pick up on currents ten per cent above the continuous ratings of the machines and the timing device was adjusted to reset the notching train in five seconds on the basis that under out-of-step conditions more than three surges would always occur in this interval. These relays were installed in November 1936 and although a number of system disturbances have occurred their performance to date has been 100 per cent correct which tends to confirm the correctness of the principles that were developed.

F. C. Poage (Ebasco Services, Incorporated, New York, N. Y.): Rewriting the equation from the author's figure 1 (*F*)

$$I = \frac{E_G - E_M}{Z}$$

We have

$$I = \frac{E_G}{Z} - \frac{E_M}{Z}$$

Let us analyze the expression E_G/Z. E_G/Z represents a fictitious short-circuit current supplied by the generator which would flow in the system *if* the internal voltage of the *motor* were removed and replaced by a short circuit as in the author's figure 4.

Likewise, analyze the expression $-E_M/Z$. $-E_M/Z$ represents a fictitious short-circuit current supplied by the motor which would flow in the system *if* the internal voltage of the *generator* were removed and replaced by a short circuit.

Thus in this case the total current I, through a given portion of the circuit, is the sum of the two fictitious short-circuit currents whose directions are, one positive and the other negative with respect to an arbitrary positive reference direction.

The voltage between conductors (or between phase wire and neutral as in conventional polyphase calculations) at any given point in the system is the *sum* of the fictitious voltages existing at this point in the two cases, first: if the internal voltage of motor is eliminated and replaced by a short circuit, as in the author's figure 4, and second; if the internal voltage of the generator is eliminated and replaced by a short circuit.

So far this analysis has followed the standard, but not commonly used method of network analysis by the method of superposition.

The author's power system may thus be considered the summation of two systems, each having but a single generated voltage (internal voltage of motor or generator) with the other generated voltage removed and replaced by a short circuit. It is apparent that each of these two systems may operate at its own frequency, and in operating at its own frequency may be out of synchronism with the other system, producing pulsating or alternating variations in voltage, current, power, etc., at beat frequency (or slip) equal to the difference between the two machine frequencies.

The illustrations and discussions offered by the author clearly illustrate the results obtained when two such systems are combined in a step-by-step synthesis from the component systems. This method may be extended to calculate the currents and voltages existing in a complicated system having (n) generators or sources of

internal voltage by building up from (n) systems, each of which has but a single generator or source of internal voltage with all other internal voltages removed and replaced by short circuits.

This analysis of the out of synchronism operation requires that voltages, currents, impedances, and power quantities be determined for each of the component systems operating at its own frequency. Each of such component systems may be analyzed by the standard methods of short-circuit analysis now well established.

It should be noted that the principal difference between the equations cited in this discussion and those used by the author is the exchange of polarity signs in the equations for voltage and current, which change should not be cause for confusion to the reader.

Temperature Limits for Short-Time Overloads for Oil-Insulated Neutral Grounding Reactors and Transformers

Discussion and author's closure of a paper by V. M. Montsinger published on pages 39–44 of this volume (January section), and presented for oral discussion at the relays and reactors session of the winter convention, New York, N. Y., January 25, 1938.

F. Von Voigtlander (Commonwealth and Southern Corporation, Jackson, Mich.) This paper suggests standards of time-temperature limits based on allowable insulation aging. The statement is made that devices with closed-type coils (that is, without oil ducts) could operate during a fault at somewhat higher temperatures than could devices with open-type coils (that is, with oil ducts), and the temperature limits for the closed-type coils are shown to be considerably higher than for the open-type coils, tables II and III. Under leif expectancy, however, it is shown that for a given set of conditions, ten operations per day are permissible with the open-type coils but only 1.3 operations per day are permissible for the closed type coils for the same conditions. The premises for the comparison of the performances of these two types of coils and their allowable temperatures do not seem clear.

From time to time it becomes necessary or desirable to use standard power of distribution transformers for grounding banks. The question then arises as to what is the permissible rating of the transformer whose rating under normal loads is known, when it is used on a one-minute of perhaps an even shorter basis as a ground bank. Could not a similar attack, as that developed in this paper, be used to determine the ratio say between the continuous rating and a short time rating of such transformers?

D. R. MacLeod (General Electric Company, Erie, Pa.): This paper by V. M. Montsinger is of value in determining the ratings of transformers for electrified railway systems. It is easy to show that two different load cycles having the same root-mean-square current will result in different temperatures. This paper and its predecessors show that the aging of transformer insulation is a function of the temperature and the time that the temperature exists.

The thermal characteristics of motors, rectifiers, converters, etc., differ widely from those of transformers and the temperature limitations of all these equipments differ. In selecting transformers for use in railway substations and on locomotives, multiple-unit cars, etc., the most economical design will only be secured by studying the load cycles on which the equipment operates. The ratings should be determined by calculating the temperature-time curves and interpreting these results in terms of the life of the equipment. This is of particular importance on rolling stock where space and weight is at a premium. Higher temperatures can be tolerated than on central station systems with the same aging because the load cycle is such that the transformers are idle or running cool a great part of the time.

This method of calculating aging units enables the engineer of a railroad to calculate the relation between the life he will obtain on an emergency load cycle with the life which he would obtain with a load cycle under normal conditions. He can evaluate the cost of reserve equipment in terms of reduced life on necessary equipment.

In short it enables the engineer to apply a transformer intelligently to fit the enconomic design of his particular system. The old method of determining ratings by the root-mean-square current failed entirely in this respect.

V. M. Montsinger: In connection with the point raised by Mr. Von Voigtlander, the higher temperatures for the closed type of coil were predicted on the fact that closed-type coils cannot be used to carry a load continuously as can open-type coils. It is, of course, true that for carrying current only during faults, open-type coils could attain higher temperature limits. For example, if 160 degrees is the safe limit for one minute for open-type coils, the one-minute temperature limit for closed-type coils to give the same aging should be approximately 135 degrees centigrade. This is covered in the paper. On the other hand, if 160 degrees centigrade is safe for closed-type coils, the temperature limit could be raised to approximately 190 degrees centigrade for open type coils. 160 degrees centigrade may be too conservative for open type coils but, as pointed out in the paper, we have no experience to justify increasing the temperature limit above 160 degrees centigrade for one minute.

I agree that it is possible to determine the ratio between the continuous rating and a short-time rating of a standard power or distribution transformer used as a grounding transformer. To determine the temperature rise of a power transformer when used as a grounding transformer, it will be necessary to obtain from the manufacturer the winding losses in terms of watts per pound or amperes per square inch. Any standard formula can be used to calculate the temperature rise.

I am glad to learn from Mr. MacLeod's discussion that he intends to make use of the method followed in the paper to obtain the ratings of electric locomotive transformers which carry heavy overloads for only a short time and with light loads or no load the remainder of the time.

While the method used in the paper was applied to a specific kind of service—faults on neutral grounding devices—there is no reason why it cannot be applied to any kind of power service.

It should be understood, however, that unless a transformer has been built to carry short-time excessive overloads, similar to locomotive transformers, there may be limitations other than the aging of the insulation. That is, the lead joints, bushings, load ratio control parts, etc., may cause trouble.

Characteristics of the New Station-Type Autovalve Lightning Arrester

Discussion and author's closure of a paper by W. G. Roman published on pages 819–22 of volume 56, 1937, AIEE TRANSACTIONS (July 1937 issue of ELECTRICAL ENGINEERING) and presented for oral discussion at the lightning protection session of the winter convention, New York, N. Y., January 25, 1938.

K. B. McEachron (General Electric Company, Pittsfield, Mass): Mr. Roman's description of the use of the mica spacers and carborundum insert for the purpose of decreasing time lag is of interest to me since I experimented with both of these arrangements some years ago. I am sure it would be of interest if Mr. Roman could give an explanation of the apparent reduction in time lag when using the carborundum. Our tests seem to indicate that the effect was rather erratic and could not be depended upon to always give the expected reduction.

There has been considerable discussion concerning high currents through lightning arresters in recent years and I notice that Mr. Roman makes some mention of it in connection with the discharge capabilities of the new autovalve arrester. It seems to me that we have to be rather careful about our thinking and consequent practice

with regard to high currents through arresters. Distribution arresters do not as a rule have the benefit of the shielding effects of overhead ground wires, and in many cases the insulation level is as high as the usual wood line designed transmission voltages, and in many cases will have as high or higher level than the steel-tower line. This indicates that the data already obtained for frequency of occurrence of currents of different magnitudes through distribution arresters may also be used for station arresters, at least until better data are available.

In general, it is safe to state that the difference between station arresters and line arresters is not altogether based upon the proposition that arresters in stations must carry more lightning discharge current than the so-called line type or distribution arresters. The choice must include factors such as protection level afforded, stability of performance, endurance for repetitive discharges and other factors of over-all reliability, but current-carrying capacity alone is not to be regarded as the criterion. As a matter of fact, when overhead ground wires are properly applied, close to the station at least, the current-carrying capacity of the arrester is not important, beyond certain limits which I will discuss.

The paper by McEachron and McMorris, presented also at this Convention, dealing with field measurements of discharge currents through distribution arresters, indicates in figure 1 that 95 per cent of the discharges recorded during 4,036 installation-years were less than 10,000 amperes and 99 per cent were less than 21,000 amperes.

Considering the fact that the wave shapes possible with lightning are not known, although it now appears from unpublished work that many shapes will be found, it seems wise from the point of view of getting the most reliable station protection to make all of the discharges conform to a certain maximum. Although we cannot control lightning itself, we can control the voltage which can reach the station by shielding the station, so that direct hits of unknown characteristics do not reach the apparatus. If waves of the 2,000 kv per microsecond, mentioned by Mr. Roman, are to be allowed in the station, then rates of rise of four kv per foot must be allowed for the distance between the arrester and the transformer, if the transformer itself were hit. Thus, with only 50 feet separation, 200 kv would have to be added to the arrester voltage. This simple calculation indicates how necessary it is to shield the station from at least the bad strokes, and this will of course shield the mild strokes also, if advantage is to be taken of the good characteristics of a lightning arrester.

It would seem that a proper policy is to pass the lightning discharge through a sieve, as it were, which is the effect of placing an effective ground-wire system over the station and the incoming circuit for at least 2,000 feet. Sufficient information is now available so that such a shielded area may be built so that one is certain that strokes to conductors within the area will be practically nil, even over a great many years. Such a construction places on the arrester a definite duty, instead of an indefinite and unknown duty, with the result that the protection afforded is predictable, and co-ordinated insulation may be designed to a definite protection level which may be demonstrated. In case the entire transmission line is not protected by overhead ground wires, a protector-tube installation can be made for most voltage and current ratings, so that flashover may be prevented when a wave of high magnitude meets the lower insulation level of the protected section.

With such an arrangement, the arrester and the overhead ground wire, together with the protector tubes if used, become a co-ordinated protection designed to function with certainty for the 220,000-ampere stroke as well as the 50,000- or 5,000-ampere discharge.

Furthermore, it seems to me, with as many multiple discharges as are now known to contact transmission lines, it does not appear to be wise to stress the arrester up to its limit when the protective shield over the station and adjacent lines will limit the duty on the arrester, maintaining greater factors of safety and increased reliability.

What I have said is not to be construed as an argument that arresters should not have a reasonable current-carrying capacity. They should, but, for station protection the arrester will do its job with greatest accuracy and precision if it is not called upon to discharge severe direct strokes of lightning. Furthermore, an arrester, which held the voltage down at its terminals to even normal line potential could not protect the apparatus if unlimited steepness of wave were permitted, unless the arrester were directly at the transformer terminals.

The best solution at present, therefore, for important installations at least, is to control both the magnitude and the maximum steepness of the incoming wave, by forcing it to travel through at least 2,000 feet of line conductor before reaching the arresters.

V. M. Montsinger (General Electric Company, Pittsfield, Mass.): I wish to call attention to what appears to be an error in line *D* of figure 9*b*. This gives the 115,000-volt class impulse strength of the transformer major insulation as 700 kv. The maximum impulse applied to a 115-kv transformer is 630 kv or 5 per cent over the bushing flashover under standard atmospheric conditions. If line *D* represents the demonstrated transformer strength it should show 630 kv instead of 700 kv. Furthermore, according to my experience in obtaining volt-time curves, it should turn up for times less than approximately three microseconds. The one-microsecond value should be about 720 kv. If line *D* does not represent the test level it does not mean anything.

D. D. MacCarthy (General Electric Company, Pittsfield, Mass.): Mr. Roman's paper "Characteristics of the New Station-Type Autovalve Lightning Arrester" contains a very interesting description of the construction and performance of this arrester.

The multigap structure which normally insulates the arrester from the power line is called a "switch gap." The individual gaps in this structure are porcelain spaced, are without shunting resistors, and have carborundum inserts in the face of alternate electrodes for the purpose of improving the impulse ratio. It would be of interest to learn from Mr. Roman how these inserts act to reduce the impulse breakdown, if they are equally effective for all rates of rise of applied voltage, and if the effectiveness is reduced by the condensation of metal which may be boiled from the electrodes by severe surges such as he shows in figure 8.

It is believed that tests made by the writer to determine the effect of carborundum inserts on gap spark potential will be of interest. The spark potential was measured on five single gaps in series with an impulse voltage rising at 50 kv per microsecond.

The following results were obtained:

Test Number	Carborundum Inserts	Impulse Ratio			Number of Measurements
		Maximum	Minimum	Average	
1	In place	2.36	1.49	1.87	10
2	Removed	2.04	1.45	1.85	10

Previous to test 1, these gaps had been sparked over ten times with 60-cycle voltage, 20 times with 1,500-ampere impulses, and 43 times with impulse and power voltage simultaneously applied. It will be observed that on these tests the carborundum inserts had no beneficial effect and that the average impulse ratio is about 40 per cent higher than the average shown by Mr. Roman in figure 4.

The multigap structure used in the new autovalve arresters to interrupt the follow current is referred to as a "quench gap." A high 60-cycle breakdown has been obtained by shunting the individual gaps with resistances, and a low impulse breakdown is obtained by spacing the gap electrodes with mica washers. Since a high 60-cycle and low impulse breakdown are equally desirable in the switch gap, it would be interesting to learn why the same type of construction has not been used in both gaps. It is of interest to note that resistance shunts have been used in the quench gap in the new arrester. The benefit of resistance shunts has been realized for some time and this principle was applied to the Thyrite station arrester brought out in 1930. Unlike the new autovalve arrester, the Thyrite arresters have always used resistance in parallel with each individual gap in the arrester, which resulted in several benefits. The resistors control the distribution of the normally applied 60-cycle voltage so none of the individual gaps is overstressed. This permits each gap to carry its predetermined share of the applied voltage. It makes the voltage

on each gap relatively independent of the effects of water or sleet on the outside of the arrester housing and also independent of the position of the arrester with respect to grounded structures. The resistance shunts also permit the design of an arrester which has a lower impulse breakdown than would otherwise be possible. It would seem that resistance shunts would be even more necessary in the switch gaps of the autovalve arrester than in the quench gap.

The valve element blocks in the *SV* arresters are cemented with a chlorinated wax. It would be of interest to know if Mr. Roman's tests agree with tests made by the writer and his associates showing that such waxes may generate explosive pressures in the event of an arrester failure.

Mr. Roman presents data in figures 6 and 7 showing that the voltage across the valve element during the discharge of impulse current depends upon the rate of rise of current as well as upon the current magnitude. Data are not given for the fastest rates of rise for low currents. Surges of this type will occur in service when the front of a steep surge is chopped by spark-over of line insulation resulting in low current amplitude but steep rate of current rise applied to the arrester. If data are available for low currents with very short fronts, it would be of value for Mr. Roman to extend the range of data of figure 7 to include currents as low as 1,500 amperes at rates of current rise of 10,000 and 20,000 amperes per microsecond. Based upon figure 7 it would seem the arrester voltage for low-current steep surges may exceed the voltage for much higher currents which have a slow rate of rise.

Figure 8 shows current and voltage oscillograms from tests on valve element blocks which were apparently made without the gap unit and without power voltage. The total time duration of the 53,000 and 79,000 ampere surges is about 12 microseconds to current zero. It is possible that surges of longer duration will impose a more severe thermal duty on the valve element even though the current magnitudes were relatively low. Mr. Roman states that "the current in the majority of the strokes is below 50,000 amperes." He also states that "we find that the new *SV* arrester will discharge the majority of direct strokes without damage to the arrester, and the arrester while discharging these high currents will offer a fair degree of protection to the connected equipment." To justify this last statement, Mr. Roman must have other data not presented in his paper. The necessary supporting facts would include data on the time to crest and duration of lightning strokes as well as on the current magnitude, the length of the circuit between the arrester and protected equipment so that the voltage drop on the circuit inductance could be evaluated, and performance data on the actual protection afforded by complete high voltage arresters taken when actually discharging typical lightning strokes with rated power voltage applied. Also subsequent test data should be obtained on the arrester to determine the effect of actual direct stroke currents upon arrester performance.

I. W. Gross (American Gas and Electric Service Corporation, New York, N. Y.): The quench-gap station-type lightning arrester described by Mr. Roman is interesting for several reasons. First, it would appear from figure 7 that the arrester has actually passed lightning currents in the order of 30,000 to 80,000 amperes, and I assume passed them successfully. Thus it would appear that we are not far remote from an arrester that can handle successfully direct stroke currents of the higher order of magnitude.

Second, rates of current rise as high as 20,000 amperes per microsecond are mentioned, as compared with our present AIEE standards for lightning arresters of 150 amperes per microsecond. While we have no knowledge that such high rates of current do exist in the field, it is gratifying to observe that they can be handled without undervoltage rise at the arrester when they do appear.

I would like to ask Mr. Roman if the characteristic performance of the arrester given in figures 4, 5, 6, and 7 is to be taken as the maximum, minimum, or average values, and what are the maximum deviations to be expected from the curve data.

In figure 9*b* I am unable to follow Mr. Roman's story on the protection of 115-kv service with the 121-kv arrester. The transformer is shown with an impulse strength of 700 kv and the lightning arrester with an *IR* drop of 530 kv, leaving 170 kv margin between the arrester and the transformer, which certainly seems reasonable. It should be noted, however, that the lightning-arrester terminal voltage is shown as a wave approximating a $1^1/_2 \times 40$ full wave. Now the full-wave impulse test on a 115-kv transformer is 540 kv, not 700, which leaves a margin between the arrester and transformer of ten kv, i.e., less than two per cent, which is less than the tolerance of measuring either the test voltage on the transformer or on the arrester.

Although the author represents the major insulation of the transformer as being 700 kv, it is not conceivable that he proposes to protect the insulation to ground which may have a strength of 700 kv and not the turn to turn and coil to coil insulation which may be only 540 kv.

Again in figure 9*b*, curve *B* depicts the time lag curve of a $31^1/_2$-inch gap, called by the author a "co-ordinating" gap. The minimum impulse flashover of this gap is shown as 525 kv, and as mentioned above the full-wave transformer test is 540 kv, leaving a margin of less than three per cent. Further, this gap flashover of 525 kv is for a positive wave and if a negative impulse should inadvertently appear in service the voltage at the gap could rise to about 585 kv, i.e., about eight per cent above the full-wave test on the transformer.

I hope Mr. Roman can prove the suitability of the new quench-gap station-type lightning arrester without working to margins of two to three per cent between the lightning arrester characteristic and the tested strength of apparatus, and also without the use of an auxiliary air gap to back up the arrester.

W. G. Roman: Mr. Montsinger and Mr. Gross have questioned the data of figure 9*b*. Since this paper was prepared the transformer subcommittee of the AIEE committee on electrical machinery has authorized the use of kilovolts rather than gap spacing as a measure of transformer strength. Since co-ordinating gaps are no longer considered desirable, curve *B* of figure 9*b* can be eliminated and the demonstrated transformer substituted. This does not change the protection picture. In the paper it was pointed out that the arrester would not protect the $31^1/_2$-inch gap. The voltage across the arrester is approximately the same as the demonstrated transformer strength of 540 kv for long waves. In other words, a traveling wave of 5,000 kv results in an arrester drop approximately the same as the demonstrated transformer strength. As pointed out by Mr. Gross, we cannot expect to co-ordinate our protection with small differences between the arrester drop and the transformer strength. If practical, the station should be designed to prevent waves of this magnitude entering the station.

In answer to Mr. Gross's question, the curves of figures 5, 6, and 7 are average values and variations of plus or minus five to ten per cent can be expected. The data in figure 4 show the actual variation during a life test on four gap assemblies. These are representative gaps and indicate the variation to be expected.

Mr. MacCarthy's tests on gaps having silicon carbide inserts show higher impulse ratios than we have found. The tests were probably made under conditions which resulted in an unequal distribution of voltage across the gaps. Under these conditions, we have found the 60-cycle breakdown of the gap assembly will be reduced more than the impulse breakdown and the impulse ratio will, of course, be increased. In the autovalve arrester the gap tube and outer casing tend to distribute the voltage uniformly across the gap assembly.

In the higher voltage arresters, grading rings are also used for this purpose. Since the switch gap is concentrated at the top of the arrester where the highest gradients normally appear, this is not as difficult as it would be if the switch gap were distributed through the length of the arrester. We have found the silicon carbide inserts effective in obtaining a reduction in impulse ratio and their effectiveness does not seem to be reduced by either high surge current or power follow current. The chart of figure 4 shows the results of a life test using a surge of 4,000 amperes and power follow. There is no apparent change.

The resistance-shunted quench gap was specifically designed to have a high power follow interrupting ability and at the same time a low impulse ratio. But, since the low impulse ratio is apparently due to corona or a similar discharge at the point of contact between

the electrode and mica gap spacer, we felt it desirable to insulate the quench gap from normal voltage. Also, by insulating the gap from line voltage the shunting resistance can be made low enough to divide the voltage equally across the quench gaps without the aid of external shields. Since there is no continuous loss due to leakage current to be dissipated, it is not necessary to ventilate the arrester.

A flashover of the autovalve blocks resulting in an arc through the chlorinated wax cementing the blocks in place can, of course, result in the generation of gas heat and can rupture the porcelain casing. However, it has been our experience that a power arc over the outside of the blocks, even without the wax, will usually result in bursting the porcelain casing.

Mr. MacCarthy asks if we have data for very high rates of rise and low crest currents. The points shown on the curves of figure 6 show the maximum rates of rise we were able to obtain at the particular crest currents shown. By using a more compact surge generator, or by placing a gap across the arrester to chop the wave on the rising front, these curves could be extended. By extrapolating the curves of figure 6 Mr. MacCarthy's point can be demonstrated. For example, the crest voltage across the blocks will be about the same for a 1,500-ampere surge rising at 7,500 amperes per microsecond as for a 10,000-ampere surge rising at 1,000 amperes per microsecond.

I believe the data presented in the paper, together with the available data on stroke currents, justify the statement that the arrester will discharge the majority of direct strokes without damage to itself and at the same time offer protection to connected equipment. Of course some of the more severe strokes may result in failure of the arrester, connected equipment, or both. The 5,000-kv surge entering a 115-kv station discussed above represents a border line case. In a paper describing arrester characteristics I do not see why we must consider inductive drops, ground resistance, etc. These are problems for the station designer and must be considered in applying the arrester, not in designing it.

I agree with Mr. McEachron that an arrester will do its job best if the station is so designed that the arrester will not be called on to discharge the more severe strokes. But I also believe it is well to know what the voltage across the arrester will be and its chance of surviving if it does discharge a severe stroke. The use of ground wires over the station and for some distance out over the lines is good practice. It is also important to place the arrester as close as possible to the equipment to be protected.

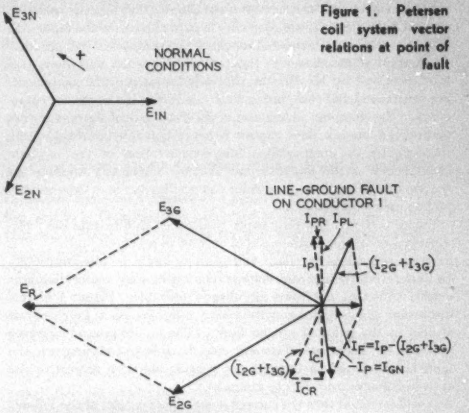


Figure 1. Petersen coil system vector relations at point of fault

E_{NG} = neutral-to-ground voltage
E_{1G}, E_{2G}, E_{3G} = line-to-ground voltages at fault (E_{1G} = 0)
E_R = residual voltage to ground = $E_{1G} + E_{2G} + E_{3G}$
I_C = quadrature component of charging current to ground from sound phases 2 and 3
I_{CR} = equivalent resistive component of current to ground due to conductor resistance, earth resistance, corona, etc.
$I_{2G} + I_{3G}$ = resultant line-to-ground current from phases 2 and 3
I_{PL} = inductive component of Petersen-coil current
I_{PR} = resistive component of Petersen-coil current
I_P = Petersen-coil current, ground to neutral
I_F = fault current

Some Engineering Features of Petersen Coils and Their Application

Discussion and author's closure of a paper by E. M. Hunter published on pages 11–18 of this volume (January section), and presented for oral discussion at the lightning protection section of the winter convention, New York, N. Y., January 25, 1938.

R. E. Hellmund: See discussion, page 304 of this volume (June section).

J. R. Eaton: See discussion, page 304 of this volume (June section).

J. R. North and **F. Von Voigtlander** (The Commonwealth and Southern Corporation, Jackson, Mich.): Mr. Hunter's paper gives a general résumé of some of the engineering features of Petersen coils and their application and it should be decidedly helpful to those concerned with the use of these devices.

There are many factors which must be carefully considered in determining the probable effectiveness of Petersen coils in a given application and, judging from our experience, these include:

1. Relative number of single-line-to-ground faults versus faults involving two line conductors.
2. Relative number of permanent ground faults versus transitory ground faults.
3. Magnitude of the in-phase component of fault current due to line resistance, insulator leakage, corona, etc.
4. System arrangement—radial, loop, multiple lines, relative location of lines.
5. Dynamic and transient over-voltages as may occur with faults at different locations, and the ability of the system insulation to withstand them.
6. Protective relay scheme and necessity for automatically clearing permanent ground faults.

Petersen coils have been in operation for some years on our operating systems and we are of the opinion that they have a definite field of application in improving the performance reliability of transmission lines. However, this experience, combined with analytical studies and field tests, does not bear out some of the broad generalized statements made in Mr. Hunter's paper regarding the effectiveness of Petersen coils and it would appear that some of these statements should be qualified.

For example, the statement is made on page 11 of the TRANSACTIONS that the Petersen coil "*eliminates* transient overvoltages of the isolated-neutral system and the short circuits of the grounded-neutral system." We believe that the author here intends to convey the thought that the Petersen coil may eliminate the *effects* of the transient overvoltages. The coil automatically extinguishes the ground fault arcs initiated by the transient overvoltage (or other causes) and maintained by the dynamic overvoltage and so prevents these arcs from spreading to other phases to cause service interruptions. The thought should not be entertained that Petersen coils *eliminate* transient or dynamic overvoltages as this can be refuted by calculation, by test, and by operating experience. The use of Petersen coils may tend to limit the extremes of both the transient and dynamic overvoltages and a properly designed application may result in a considerable reduction of these overvoltages. Nevertheless, for certain conditions of system layout, fault locations, coil locations, etc., line-to-ground voltages well in excess of the normal line-to-line voltages may still be obtained during ground faults, even though the coil is in tune and successful arc extinction is obtained. Furthermore, the coils mitigate only the effects of transitory single-line-to-ground faults and have no effect on two-line-to-ground faults or line-to-line faults.

The statement is made on page 12 that "theoretically the leading

charging current of the system is neutralized by the lagging inductive current from the coil, which results in zero current in the fault. In practice, this is approximated as closely as conditions will permit." Evaluation of the theory of Petersen coil operation will show, as is later discussed by Mr. Hunter, that only the quadrature components are neutralized and that during fault conditions the in-phase components of the charging current and of the Petersen-coil current are not neutralized, so *zero fault current* is never actually obtained, either theoretically or practically. This consideration of the in-phase components of the fault current is very important because the success or failure of the particular coil application may depend very largely upon this quantity.

Figure 1 of Mr. Hunter's paper is intended to illustrate the "vector relations of the components of current in a ground fault." This diagram is quite abbreviated and possibly might be misinterpreted. In illustrating current and voltage relationships by vector diagrams double subscript notations are always desirable. Figure 1 of this discussion shows the complete vector relations on a Petersen-coil system at the point of ground fault. The line-to-ground charging currents, the Petersen-coil current, and the unbalanced current in the fault are all shown in their proper relationship with respect to the system voltages from line to ground.

It will be noted that the current components consist of the following vector quantities:

$I_C = (I_{zg} + I_{ng}) - I_{corona}$
I_P = inductance + resistive components of coil current
I_F = vector resultant of I_C and I_P

It is mentioned on page 13 of Mr. Hunter's paper that test results may give charging currents as high as 50 per cent in excess of calculated values. This should be true only if certain important factors such as system layout, earth resistivity, overhead ground wires, and other factors affecting the zero-sequence impedance are not taken into account. When all these factors are considered, our studies on 44-kv and 138-kv systems have indicated that the charging current may generally be calculated with an accuracy of about ten per cent plus or minus and this has been substantiated by tests. The in-phase current components may also be predicted, but with somewhat less accuracy.

In the discussion of general applications on page 14, the author observes that theoretically one Petersen coil is sufficient to protect all parts of an entire system which are metallically interconnected. In an extensive system, the use of only one coil may permit such large in-phase components of fault current to exist that the effectiveness of the one coil would be considerably mitigated, whereas by the use of a number of smaller coils the charging current may be more fully compensated in the network branches.

Table I under "Remarks" should be corrected to read, "140 miles of line without ground wires," instead of "but 40 miles of line is without ground wire."

Referring to the "Summary" in Mr. Hunter's paper, item 3 may not be exactly clear as to the level of insulation referred to. With the overvoltage conditions which have been found by test to exist on Petersen-coil systems, it would seem that caution should be exercised in applying these coils to a system insulated only for what might be considered solidly grounded neutral operation with "full neutral displacement."

Item 4 should also be qualified, since the effectiveness of the Petersen coil depends upon a number of other factors such as: corona current, in-phase component due to unbalanced conditions, etc., as well as the size of the system and its circuit arrangement.

Mr. Hunter has called attention to the importance of the rate of rise of system recovery voltage at the fault location. This factor must be carefully considered in analyzing coil operation. Apparently, from the information available in oscillographic records of Petersen-coil systems, there is a relatively slow rate of rise of recovery voltage after the arc breaks and thus but little tendency for arc restriking. This rate of rise of recovery voltage is a governing factor in determining the maximum amount of fault current which may be successfully interrupted.

This discussion is intended to emphasize and to elaborate upon some of the statements made in this paper. It is not intended to in any way disparage the effectiveness or the desirability of Petersen coils when all the pertinent factors have been considered in their application to a power system. It is our purpose merely to point out the necessity for considering all the factors involved, particularly if the power system be of any extent.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): One of the discussers has apparently become so enthusiastic about the use of Petersen coils that he seems to think they might be used to advantage on underground cable systems operating at between 3 kv and 33 kv, especially since Petersen coils have been used on some underground systems in Europe. Almost all of the multiple-conductor cable purchased in this country has been obtained on the basis of neutral grounding, and the insulation thickness between the conductor and ground has been made substantially less than the insulation thickness between conductors. If the Petersen coil is used, then there may be a fault on one phase with the other phases operating with the full delta voltage between conductor and sheath for a considerable time. Such operation may be permissible for some cables, but it is certainly outside of the contractual arrangements and probably is not feasible for many installations from the standpoint of the strength of the insulation. In Europe there are comparatively more systems where the insulation thicknesses are the same between conductor and sheath as they are between conductors.

It is to be noted that the use of the Petersen coil on an underground cable system is not so beneficial as on an overhead system, because the fault does not clear itself. A faulted three-conductor cable usually could not be kept in operation very long, even with the help of the Petersen coil, since the residual unbalance current through the fault would very quickly burn the insulation of the other two phases and result in a two-phase or three-phase short circuit. The larger the system, the quicker the other phase would become involved so there is little likelihood of being able to keep a faulted three-conductor feeder in service until it is convenient to repair it, at least for our cable system.

The use of the coils on a system having both overhead and underground distribution such as our four-kv system does not seem to have any attraction from the standpoint of diminishing the effects of lightning. The overhead construction is such that flashovers limit the surges on the overhead system to 300 or 400 kv, which means that the resultant lightning impulses traveling into the cable are only a small fraction of the impulse strength of the cable insulation. When all kinds of troubles were taken into account, we found that only about ten per cent of our four-kv circuit interruptions might have been eliminated by the use of Petersen coils.

E. M. Hunter: Messrs. North and Von Voigtlander have summarized very nicely some of the factors which should be considered in estimating the probable improvement in service to be obtained by installing Petersen coils to an existing power system. They have very aptly pointed out that the success of a Petersen coil as a service protective device depends upon the faults being single phase to ground. On many systems at least 70 per cent of all the faults are single phase to ground. On some systems it is possible to raise the degree of protection obtained by such supplementary aids as down wires on wood poles and low footing resistances which tend to keep the flashovers single phase.

On the other hand, service protection as such is not always the major issue. The reduction in maintenance on connected apparatus has more than justified the addition of Petersen coils to some systems which were formerly operated with the neutral isolated.

These discussers have stressed repeatedly the importance of the in-phase component of current in the fault. The Consumers Power Company 140-kv system which has Petersen coils has a relatively large in-phase component of current resulting from corona. It is probable that the magnitude of this component of current on this system is in excess of that to be expected on many systems. As far as I have been able to learn, of the more than 1,700 applications of Petersen coils in the world today, all have successfully functioned to quench transitory arcs to ground without the aid of any means to re-

duce the in-phase component of current. Fault tests have been made on a 33-kv Petersen-coil-equipped system with more than 1,300 miles of interconnected lines without excessive in-phase components of current being recorded. However, there undoubtedly is some maximum limit to the current that will successfully extinguish itself even with the relatively unstable arc that is obtained when the Petersen coil is properly tuned and where corona is present, the in-phase component of current warrants consideration.

The statement in my paper in connection with the accuracy of calculating system charging current is to the effect that measurements on 33-kv systems give currents that are as high as 50 per cent in excess of those calculated by the aid of Maxwell's coefficients. For those who wish to check this, a measured value of charging current in a ground fault on a 33-kv line with three-foot delta spacing and 4/0 conductor mounted on 30-foot poles was 0.22 amperes per mile. On high-voltage lines, there has been in general a closer agreement between the currents calculated by these coefficients and those obtained by test.

In connection with vector diagrams, the one in the paper has been drawn by viewing the system from the neutral where the Petersen coil is located to the point at fault while the discussers' is apparently drawn from a position at the fault looking into the system to the neutral where the Petersen coil is located. An examination of these two vector diagrams shows that in general they both correctly represent the neutralizing of the current in a ground fault. For example, on the discussers' diagram, although not shown, the system neutral is located one-third the way up the vector E_R from the point of fault. Drawing in a voltage vector from the neutral to phase one E_{1n}, on the discussers' diagram, will place the vector relations of system charging current and Petersen-coil current in the same relative positions that they occupy in the diagram in the paper.

The two diagrams differ in the presentation of the system residual voltage. The discussers' diagram shows the residual voltage E_R as three times the magnitude of the system line-to-neutral voltage E_{1n}. It is well known that such a voltage exists on a system only on the secondaries of those potential transformers which are connected to measure residual voltage. To show the residual voltage as three times the system line-to-neutral voltage and three times that actually existing on a system may lead to the erroneous conclusion that the application of a Petersen coil to a system will cause to be impressed upon connected apparatus three times the line-to-neutral voltage during each ground fault. Since this is decidedly not the case, this vector diagram with its residual voltage E_R should be shown with an explanation of what it actually represents.

Mr. J. R. Eaton has given a very interesting discussion of the recovery-voltage problem as it is associated with Petersen coils. It is to be hoped that he will extend this investigation and present a more detailed story of the correlation of his theory with actual tests.

Mr. Herman Halperin discusses the application of Petersen coils to cable systems. At the present time there are no Petersen coils on cable systems in the United States so that we have no operating experience from which the efficacy of this type of application can be judged. However, several installations of Petersen coils on cable systems have been made in England in the last year or so and since in the past English grounding practice has closely paralleled our own, it is of interest to learn of their experience with Petersen coils on cable systems. This has been given in a recent paper presented in London in December 1937, "Line Protection by Petersen Coils, With Special Reference to Conditions Prevailing in Great Britain," by H. Willott Taylor and P. F. Stritzl, which is to be published soon in the Institution of Electrical Engineers *Proceedings*. This paper reports in particular three separate single-phase faults on three-phase 11-kv cables, which remained single-phase for extended periods. In each case, the Petersen coil permitted the cables to be kept in service until repairs could be made. From these service reports, it appears logical to conclude that the application of the Petersen coil to a cable system warrants consideration.

Mr. R. E. Hellmund is of the opinion that the Petersen coil is not the best solution of a protective problem under *all* conditions, and I am fully in agreement with him on this. Duplication of circuits, overhead ground wires and counterpoises, expulsion protective tubes, and immediate reclosure of oil circuit breakers should all be considered with the Petersen coil and the one best suited for the application selected. Comments on these various other methods of protection will be found in the article "The Application of the Petersen Coil" by E. M. Hunter, in the *General Electric Review* for December 1936.

A New High-Speed Distance-Type Carrier-Pilot Relay System

Discussion and authors' closure of a paper by E. L. Harder, B. E. Lenehan, and S. L. Goldsborough published on pages 5–10 of this volume (January section), and presented for oral discussion at the relays and reactors session of the winter convention, New York, N. Y., January 25, 1938.

T. G. LeClair (Commonwealth Edison Company, Chicago, Ill.): Like all other improvements in the art, carrier relaying brings up additional and related problems which must be solved. Some of these problems which have arisen in connection with application of carrier relaying in Chicago may be of interest because they are likely to occur on other transmission systems.

Induced Currents

For the protection of two long overhead lines which parallel closely, a ground fault on one line introduces serious relaying problems due to induction. On the particular application in Chicago the current induced in the parallel line under maximum conditions will be greater than the fault current due to an actual fault on this line at minimum conditions.

In the case of two parallel lines supplied by a single bus and transformer, the induction is no problem, because the relative direction of the induced current and the transformer neutral current is used to obtain the directional effect. However, in the case of two lines frequently operated on separate bus sections supplied by separate transformers, the induced current flows through both the line and transformer neutral circuits and may trip the relay in error. This problem has been solved quite simply in one case by polarizing the directional relay on each line with the vector sum of the neutral currents in the transformers on both lines. In this case current in the faulted line and the net polarizing current (fault current minus induced current) are in the same direction on the faulted line and in opposite directions on the unfaulted line.

The problem is more complicated where the two lines have a parallel throughout most of their length, but have different destinations. For this case a solution which will work in some instances is the use of phase-to-ground voltage relays to prevent tripping on overcurrent unless the voltage on one phase has been reduced below a predetermined value. Also, negative-sequence current or voltage relays may be used. Another suggestion which has been made, and on which we would be interested in comments by the authors, is that of balancing out the zero-sequence current in phase-directional power relays. This can be accomplished by the installation of three three-to-one secondary current transformers in the neutral circuit of the secondaries of the main-circuit current transformers and con-

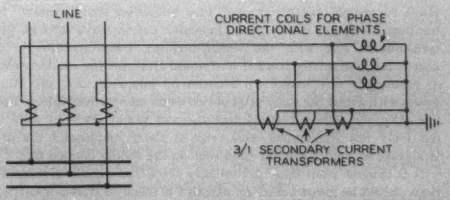


Figure 1

necting each of these three-to-one current transformers to the current circuit of the phase-directional relays, as indicated in figure 1 of this discussion.

This application should be satisfactory where the overhead line has the normal number of transpositions so that the induced current will be distributed equally in the three phases. By the addition of these secondary current transformers, which add a third of the total ground current to the current from each main current transformer, the induced current will be balanced out and fail to appear in the relay. However, by actual fault on the line where the ground current appears in one phase only, this will not be the case and the relay will operate satisfactorily.

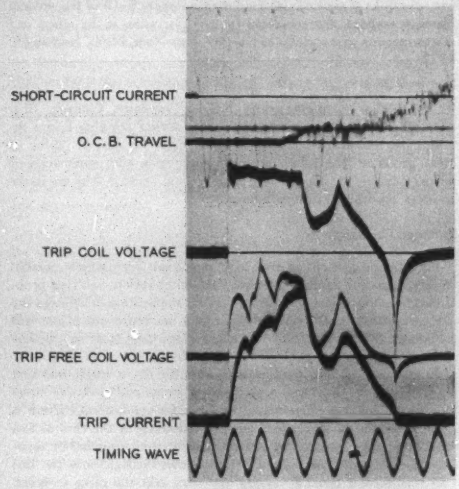


Figure 2. Performance of normal trip circuit, sustained fault

Application to Underground Cable

The application of carrier relaying with which we are concerned at the moment is that of a line having underground cable over six miles of its length and an overhead line for approximately 30 miles. It has been found that in some cases it is quite difficult to send the carrier frequency current through the underground cable. For the Chicago application we had a specially favorable opportunity to compare the transmission characteristics of an underground line with and without sheath-bonding transformers to reduce cable-sheath losses. We have two lines in parallel in the same underground duct section, each consisting of three single-conductor lead-covered cable. One of these lines is solidly bonded. The other has insulated joints in the cable sheaths, with the sheaths across the joints connected together through sheath-bonding transformers. It has been found quite difficult to transmit a carrier wave through the transmission line with the sheath-bonding transformers. On a simple test the solidly bonded line would transmit the carrier wave at practically any frequency between 50 kilocycles and 140 kilocycles with about the same attenuation as on an overhead line. The line with the sheath bonded transformers would transmit only a relatively few frequencies, and even at these frequencies the attenuation was much greater than that on the solidly bonded line.

It is evident from these preliminary tests that careful considerations should be given before an attempt is made to transmit carrier frequencies over underground transmission lines with an artificial impedance inserted in the cable sheath circuit. It is apparent that the circuit for the carrier wave is normally the conductor of the transmission line and that the return path is the sheath of the same cable instead of the general ground plane.

H. P. Sleeper (Public Service Electric and Gas Company, Newark, N. J.): This paper describes a system of carrier-pilot relay protection which compares the indications of instantaneous directional relays at the two ends of a transmission line and trips or blocks in accordance with this information which is communicated between terminals by means of a carrier-pilot channel which is normally not operative. It is now considered the up-to-date relay protection of this general type and relay systems operating on this principle have been in service for several years and are quite successful.

This scheme, which has been boiled down from about 15 years' experimentation with carrier-pilot relaying, has apparently arrived at a stable and fairly dependable stage. Having been until very recently, only an interested observer of this type of relaying, but having followed it on paper for many years, there is to my mind only a single fundamental fallacy in the present perfected scheme. I refer to the fact that when a fault occurs on a power system with this type of protection on all lines, it is necessary for the relay protection on all good lines, as well as all faulted lines, to operate correctly to secure selective relaying of the defective line. This is, of course, only an extension of any ordinary system of directional relays where direction alone locks out the operation of nearby breakers on good lines, but by virtue of the transmission of information of such elements in the carrier scheme to the far line ends, it requires the correct operation of considerably more elements than with standard relaying. Unfortunately, I have no solution for the problem, but there seems to be opportunity for further development work.

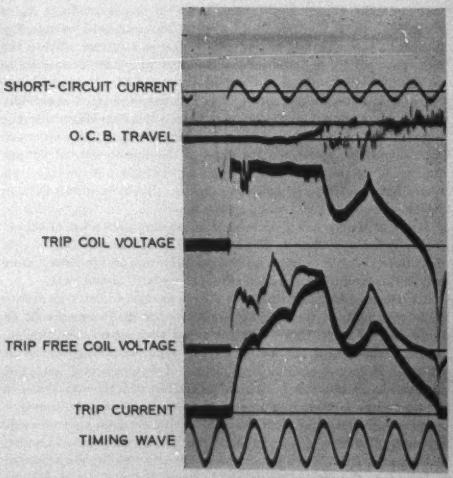


Figure 3. Performance of normal trip circuit, one-cycle fault

The authors of this paper recommend the use of several steps of distance relays to effect protection of a line unit; one to operate independently of the carrier system for a considerable number of faults on the line and back-up protection of the carrier; a second step to operate for end zone line faults and bus faults at the end of the protected section; and third step for general back-up protection for all faults beyond the line unit in question.

To the writer it would seem to constitute more efficient, depend-

able, and economic relaying to omit all back-up features and depend upon the carrier system alone for protection for all faults on the line in question. Similarly, the carrier protection on the next section of line would be likewise depended upon for its proper operation and no back-up relays provided in the carrier equipment. The busses would have their own differential relay protection which would be depended upon to clear its own faults, preferably, of course, with sectionalizing breakers to maintain service on the good part of the bus. Furthermore, the omission of all accurate distance-measuring elements on each line enables high-tension potential transformers to be omitted and only low-tension potentials used on the fault detector element, thereby effecting the saving of a considerable amount of money, at the same time obtaining more dependable operation of the directional elements by virtue of the impedance drop through the step-down power-transformer banks.

One problem which arises in connection with high-speed carrier relaying, or any type of high-speed relaying, and which has been recently solved by this writer in a manner believed to be novel, is that of preventing improper operation of such relays during transient short circuits, either phase-to-phase or -to-ground. There are many causes for such transient faults, which were very completely described in a paper entitled "Power System Faults to Ground" by Gilkeson, Jeanne, and Davenport, published in the April 1937 issue of ELECTRICAL ENGINEERING. Such faults, which ordinarily last only a portion of a cycle, but may continue for as much as one cycle, will cause improper operation of circuit breakers on at least one end of a line with any system of modern high-speed relaying. Since expulsion tubes will nearly always cause such operation, it is absolutely necessary that the relays be capable of distinguishing between

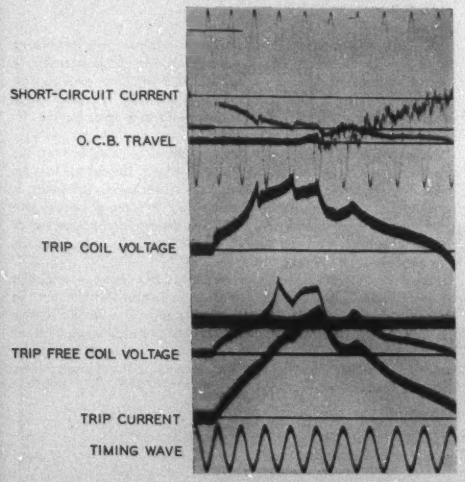


Figure 4. Performance of modified trip circuit, sustained fault

this and a legitimate fault which will be sustained, if not relayed out.

The solution worked out by the writer consists of the use of a reactor and condenser in the d-c trip circuit of the high-speed relays. Without such auxiliaries the reactance of this circuit is sufficiently low to allow the direct current to build up almost instantly when the relay closes contacts; and even though the contacts open a cycle later when the fault disappears, the arc will be maintained sufficiently long across the contacts to permit the high-speed breaker to open. The introduction of a properly proportioned additional reactance in series with the breaker trip coil and the application of a proper capacitance across the relay contacts prevents this in the following manner. When the d-c circuit is closed at the relay contacts, the trip coil current starts to build up, but very slowly because the L/R time constant of the d-c circuit has been considerably increased. Hence, the current to be broken on the relay contacts is much smaller than formerly after one cycle of time. However, this alone is not depended upon but the current is actually reduced to zero at the relay contacts by the creation of an oscillatory circuit caused by the exchange of energy between the condenser and the inductance of the trip coil circuit. Actually, the oscillogram shows

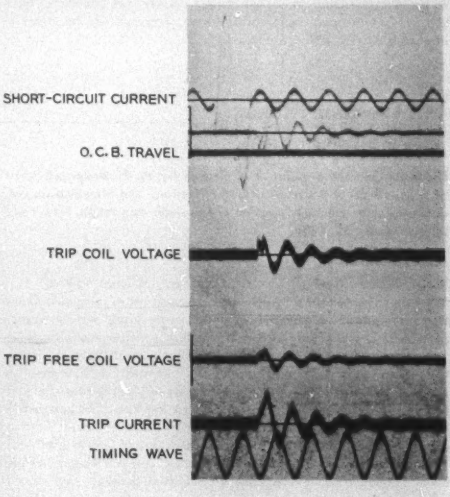


Figure 5. Performance of modified trip circuit, one-cycle fault

that several oscillations occur, and of course, the direct current arc is broken at current zero.

In actual operation the use of a two-microfarad condenser and a reactance of one henry, when used in the trip coil of a standard 37-kv circuit breaker, gave dependable operation so that a one-cycle fault was always removed without causing the circuit breaker to trip. Likewise, of course, a one- to two-cycle delay is introduced into the normal tripping operation of the breaker when a sustained fault occurs. The operation of the scheme is clearly shown in figures 2, 3, 4, and 5.

B. E. Lenehan and **S. L. Goldsborough:** Mr. LeClair's suggestion for removing the zero-sequence components from star-connected phase relays may have certain applications. The delta connection used in the paper removes the zero-sequence components. When system conditions are such that ground relays are not required, it is a suitable method of preventing induced current from tripping.

Sometimes, local conditions require certain limited power oscillations to be permitted without tripping. Star-connected phase relays will occasionally allow these oscillations to occur where otherwise out-of-step blocking would be required.

Where relays are required to operate on ground currents smaller than full-load current, separate ground relays are required. When maximum induced current is greater than minimum fault current, some other factor such as negative-sequence current line-to-neutral voltage or station-neutral current has to be introduced to properly select the operation desired. Each location has to be considered by itself to find the best additional factor to use.

We have carried on experiments in improving the transmission

over an underground cable of the Public Service Corporation of New Jersey, which is equipped with sheath-bonding transformer. The joints were by-passed with four microfarad capacitors to simulate a continuous sheath at carrier frequency.

The transmission of the cable was greatly improved, approximately 30 decibels, in the ten-mile length. There are other factors to be considered, voltage induced in the sheath by switching surges and faults, being high enough to require protective gaps on the capacitors to prevent damage to capacitors or cable sheath insulators. A careful study will be required for each individual case to determine whether the power cable should be used for the carrier or a separate channel provided for it. As Mr. LeClair's tests have shown, underground construction does not necessarily bar the use of carrier-current relay protection.

The Thyratron Motor at the Logan Plant

Discussion and author's closure of a paper by A. H. Beiler published on pages 19–24 of this volume (January section), and presented for oral discussion at the electronics session of the winter convention, New York, N. Y., January 25, 1938.

W. C. White (General Electric Company, Schenectady, N. Y.): The references to tube difficulties in this paper are of interest because they are typical of what occasionally occurs along wholly unpredictable lines when new devices are combined with new applications.

Structurally and except for slight differences in characteristics, the tubes used in this thyratron motor are identical to those used by the hundreds in thyratron control of seam welding during the past few years. In this welding-control application, the tubes have given satisfactory life and the nature of failure "cathode heater burned open," which is listed as the most common cause of failure in table I, has been absent. Careful analysis of this "cathode heater burned open" indicates that it is basically a mechanical breakage of a welded connection.

On the basis of all known factors, this thyratron-motor application represents less severe service on the tubes than that encountered in welding-control practice. Certainly the failure of welds, which commonly results from frequent intermittent operation and marked mechanical vibration, is absent in welding control. However, the fact remains that such failures did occur to an abnormal degree and, therefore, there must have been a special contributing factor in this thyratron-motor cubicle, which was probably a mechanical vibration of some unsuspected frequency. This might have originated either from the machinery in the vicinity or connected with the actual operation of the cubicle controls. A very simple and minor change in this small welded connection appears to have entirely eliminated this difficulty.

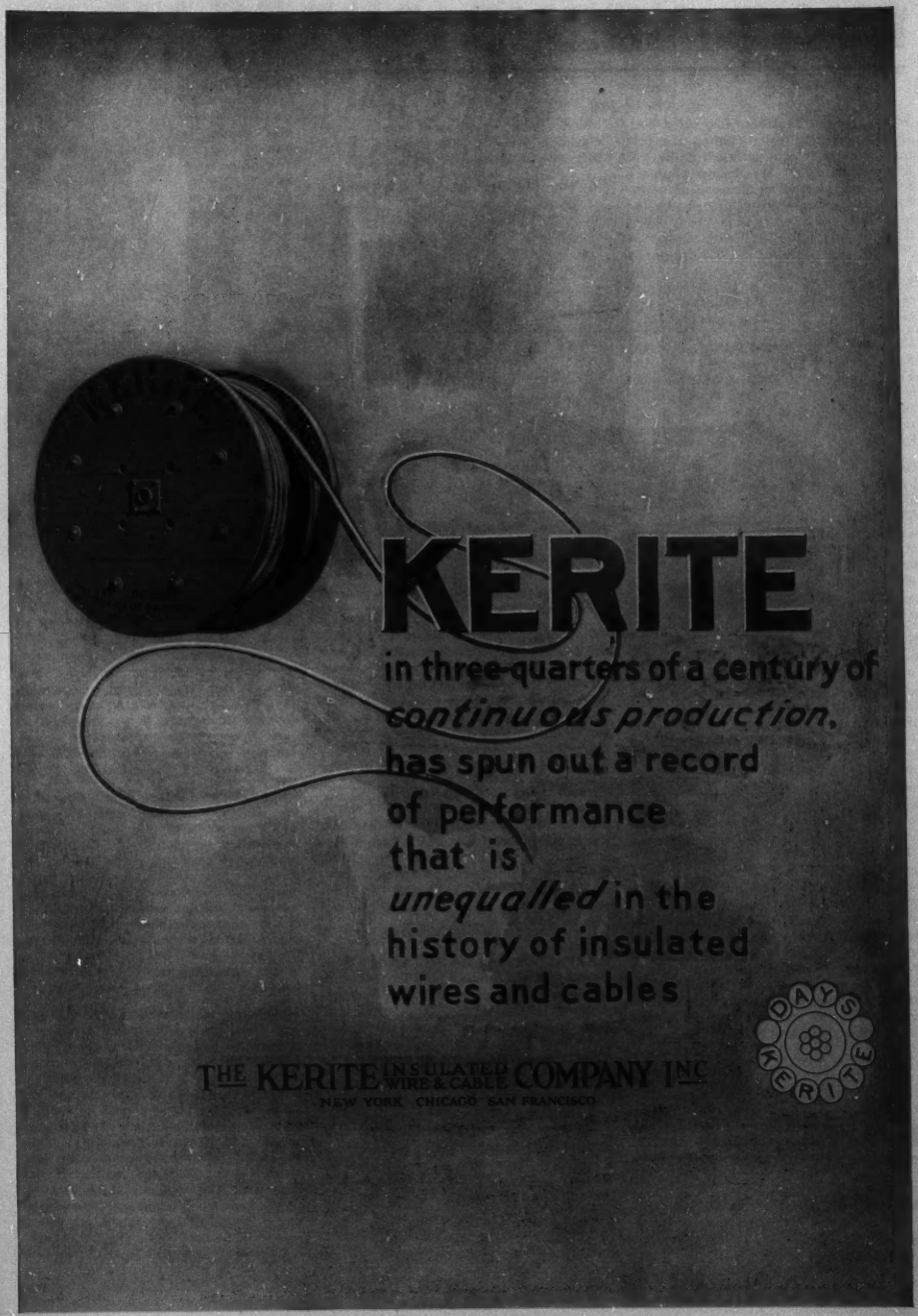
A paper on such unpredictable occurrences in other electrical fields, in addition to those that have been encountered from time to time in connection with tube applications, would undoubtedly prove interesting reading. Often first-class detective work is essential to get at the bottom of such unforseen combinations of factors.

Philip Sporn (American Gas and Electric Service Corporation, New York, N. Y.): The thyratron motor, like many other tube applications that have been developed in the past decade, again demonstrates the ease with which the solution of problems involving variation in flow of current for the obtaining of proper equipment characteristics, whether they be voltage, torque, speed, or related quantities, can be obtained by the use of electronic devices. The operating experience cited by Mr. Beiler clearly shows that everything expected in the way of performance at the time the application was first developed has been attained in practice. However, it also strikingly brings out the one serious weakness of electron tubes—their short life—due mainly to the lack of sufficient experience in the building of tubes, particularly those carrying fairly heavy current. I have on other occasions pointed out that until we get to the point where engineers begin using these tubes in quantity, we cannot expect major improvements either in cost reduction or in the qualities of reliability and life comparable to that attained with other more standard classes of equipment. The experience with the tubes on the motor again demonstrates this; further it shows that the causes of the difficulties can in most cases be determined and having been determined, remedies worked out. However, what there is lacking is the integration of sufficiently extensive experience under sufficiently varying conditions. Given that experience there is no reason why this one problem in tube applications cannot be solved.

A. H. Beiler: Mr. Sporn's point about additional experience being required with electronic control is well taken. It is natural for central station engineers to hesitate before applying such control to large power station auxiliaries, but once the ice is broken there should soon be available sufficient data to furnish clues for the detective work which Mr. White mentions.

Regarding Mr. White's other comments, it is possible that the shocks incident to removing and replacing cells in the cubicle may be partially responsible for the cathode-heater breakages, but I cannot help but feel that a contributing cause may be some at present obscure phenomenon associated with this particular application of thyratron tubes. Perhaps studies of the effects of commutation may shed additional light on this problem.

Mechanical vibration from an unsuspected frequency as suggested by Mr. White is a possibility. However, in view of the fact that the motor and its draft fan are the only rotating apparatus anywhere near the cubicle and that they run very smoothly this appears as a rather unlikely explanation. Within the next year there should be evidence indicating whether the new method of connecting the cathode heater has been really effective.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Industrial Notes

Westinghouse Business Improving.—Although incoming orders during the first quarter of 1938 were less than during the first quarter of 1937, Westinghouse business for March showed an increase of nearly $4,000,000 over February. Orders for the first three months of this year totaled $37,998,569. During the same period of 1937 they were $74,242,584. March orders were $15,126,588; those for February were $11,549,127. On March 31, 1938 unfilled orders amounted to $53,651,814 as compared with $60,298,087 on January 1.

Utilities Service Appointment.—Goodyear & Hammersley, 120 Greenwich St., New York City, have been appointed sales agents for Utilities Service Company, Allentown, Pa., manufacturers of distribution, transmission, underground and street lighting equipment.

General Electric Sales Report.—Sales billed by the General Electric Company for the first quarter of 1938 amounted to $65,086,557 as compared with $73,412,420 for the corresponding period in 1937, a decrease of 11 per cent. Orders received during the first quarter of 1938 amounted to $65,376,400 as compared with $105,747,030 for the same period in 1937, a decrease of 38 per cent.

New Westinghouse Plant.—Early construction of new manufacturing and warehouse facilities at its East Springfield, (Mass.) works is announced by the Westinghouse Electric & Mfg. Co. The buildings will be of latest improved design for modern factory construction. The expansion program is partly to take care of the large amount of business, especially air conditioning, that seems certain in connection with activities in new types of housing, and partly to accommodate certain manufacturing operations which will be transferred from the Chicopee Falls works. The new manufacturing building will have approximately 100,000 square feet of floor space. The warehouse will be two stories and will include approximately 230,000 square feet of floor space. It will be used to store finished products at present warehoused in leased buildings at Chicopee Falls and Springfield. These products include beverage coolers, water coolers, commercial refrigeration units, air conditioning equipment, electric fans, vacuum cleaners and room heaters.

Trade Literature

Highway Lighting.—Bulletin GEA-1097B, 8 pp. Describes luminaires and accessory equipment for highway lighting. General Electric Co., Schenectady, N. Y.

Fans.—Catalog X2459, 16 pp. Describes electric exhaust fans and ventilating fans; includes data on methods of installation for maximum benefits. The Emerson Electric Mfg. Co., St. Louis, Mo.

Motors.—Bulletin, 4 pp. "Asbestos Protected U.S. Motors." Describes the method used in insulating and winding these motors with asbestos insulation. U.S. Electrical Motors, Inc., Los Angeles, Calif.

Power Factor Correction.—Booklet 158, 24 pp. Consists of a reprinted article describing the manner in which a substantial annual saving is effected in a manufacturing plant through improved power factor. The Electric Controller & Mfg. Co., Cleveland, O.

Cable Racks.—Bulletin 103, 16 pp. Describes cable racks for manhole and vault installations. These racks are provided with or without movable porcelain insulation. Metropolitan Device Corp., 1250 Atlantic Ave., Brooklyn, N. Y.

Instruments.—Bulletin, 32 pp. "When You Can Measure." Outlines the contributions of General Electric engineers and scientists to the art of measurement and describes the method of instrument design, construction and testing. General Electric Co., Schenectady, N. Y.

Wires and Cables.—Bulletin, 48 pp. "A Salesman's Own Guidepost to Wire and Cable Selling." Consists of a brief resume of each type of a complete line of wires, cables, cords and cable accessories; their construction, application and market. Issued primarily for the electrical wholesaler's representative. General Cable Corp., 420 Lexington Ave., New York City.

Pyranol Capacitors.—Bulletin GES-1757, 36 pp. "Pyranol Capacitors for Central Station Application." Gives a thorough photographic description of the steps in the production of G-E Pyranol capacitors, from the careful selection and processing of raw materials to the final testing of the completed product. General Electric Co., Schenectady, N. Y.

Transformers.—Bulletin 2172-B, 8 pp. Describes "Outage Free High Voltage Distribution Transformers," built for 6900 and higher voltage classes. Considerable space is devoted to description of improved impulse strength and other features that insure economical and trouble-free operation. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Outdoor Power Switching Equipment.—Catalog GEA-627, 176 pp. A comprehensive volume on standard station equipment including insulator units, bus supports and accessories, disconnecting switches, outdoor fuses, air switches, a complete line of electric power connectors, etc. General Electric Co., Schenectady, N. Y.

Pintype Insulators.—Bulletin 638-H, 6 pp. Describes radio-proof, pintype insulators known as Silentypes. The theory of the design is outlined; test apparatus is described for comparing radio characteristics, and mention is made of the availability of copper and aluminum coatings and the high adhesion value of these metal coatings. Ohio Brass Co., Mansfield, O.

Cables.—Bulletin GEA-2623, 32 pp. Describes varnished-cambric insulated cable, construction and characteristics, as well as applications. Includes simplified data on how to select conductor size. Among the new types treated is Glyptal cloth interlocked cable, which has proved well suited to indoor wiring. General Electric Co., Schenectady, N. Y.

Network Cable.—Bulletin C-39, 8 pp. Outlines characteristics of ANW cable, described as a major development in network cable. A general description of its use in industrial applications and large buildings is given based on the National Electrical Code, indicating that this cable is now suitable for use in places where heretofore only lead covering has been acceptable. Anaconda Wire & Cable Co., 25 Broadway, New York City.

Oil Testing Equipment.—Cat. Sec. 44-200, 8 pp. Describes field and truck type outfits for testing insulating oil in transformers, circuit breakers, etc., and the operation of high-voltage testing equipment to be used in cable testing. A large kilovolt-ampere capacity transformer is required for such testing because of the high electrostatic capacity involved. Each type of equipment is illustrated and tables include list prices and styles. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Balancing Machines.—Bulletin 14, 24 pp. Describes type EO static and dynamic balancing machines. This equipment is represented as ideal for balancing, both statically and dynamically in one operation, any small, high speed rotating parts wherein an accurate balance is a prerequisite for quiet operation and trouble-free service. Tinius Olsen Testing Machine Co., 500 North 12th St., Philadelphia, Pa.

Glass Covered Magnet Wire.—Bulletin, 4 pp. Describes Vitrotex (glass fibre insulated) magnet wire. Outstanding characteristics are the ability to withstand high temperatures for a long period of time, high dielectric strength and insulation resistance. The insulation is mechanically strong and Vitrotex wires can be wound into coils by the same general methods used for other magnet wires. Space occupied by this type of wire is less than double cotton of the same gauge. Anaconda Wire & Cable Co., 25 Broadway, New York City.

Socket Instruments.—Bulletin B-2136, 20 pp. Describes and illustrates installations, applications and economies of these "plug-in" instruments. Ammeters, voltmeters, wattmeters, watthour meters, recorders and test jacks may be conveniently plugged into these sockets. The test jack is supplied with cable leads for connection to conventional instruments or analyzers. These socket instruments' provide accurate facts about power costs and equipment performance. The location of instruments are shown in a circuit diagram. A complete line of electrical instruments are shown, including portable instruments, medium switchboard instruments, large switchboard instruments and socket instruments. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

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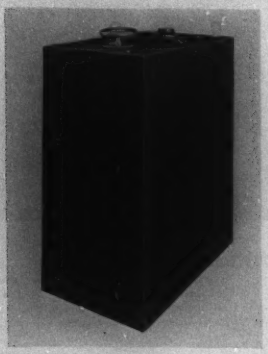
New Products

Brush Type Wire Stripper.—A new motorized brush type wire stripper especially designed for rapid, fine wire stripping has

been introduced by the Ideal Commutator Dresser Co., 1053 Park Ave., Sycamore, Ill. This machine cleanly strips cotton, silk, enamel, string asbestos covered wire, and fine "Litz" wires. It is especially suitable for stripping rectangular or square conductors and removes gummy insulation embedded in stranded wires. Heavy metal guards in front of the revolving wire brushes and over the driving belts protect the operator's fingers. It is driven by a 1/4 hp motor.

Transformer Type Arc Welder.—A new transformer type arc welder, the Trans-Arc, has been developed by the American Transformer Co., 178 Emmet St., Newark, N. J.



The equipment offers an exceptionally low open-circuit voltage and a relatively high voltage for maintaining the arc. These operating characteristics are secured through the use of a new circuit which utilizes condensers in combination with a welding transformer. The welding current is controlled by means of a continuously variable auto-transformer regulator known as the Transtat, which varies the voltage across the condensers. This method provides complete flexibility of control and maximum economy of operation in machine which is both compact and quiet in operation. The Trans-Arc is manufactured in three popular sizes (150 amp., 300 amp., and 500 amp.) for operation on either 230- or 460-volt, 60-cycle circuits. Descriptive bulletin is available.

Glass Insulating Tapes.—New electrical insulating tapes, woven entirely from glass yarns, have been developed by the Corning Glass Works, Corning, N. Y. These tapes, with the appearance and flexibility of ordinary textiles, are intended for the insulation of coils for motors, generators, transformers, and for cables and other electrical conductors. As they are composed solely of glass, they not only have exceptional electrical properties and chemical

resistance, but have the ability to withstand temperatures far in excess of the limits specified for class B high temperature insulation. They impregnate readily with resins, gums, and varnishes to form an insulation impervious to moisture and of high dielectric strength. The flexibility and textile properties of these tapes are obtained from the extreme fineness of the glass fiber, which is from 1/15 to 1/20 in diameter of a human hair.

Self-Supporting Pillar Jib-Crane.—The Harnischfeger Corporation, Milwaukee, Wis., has developed a new self-supporting

pillar jib-crane for work in side bays, low headroom areas and other confined spaces where overhead traveling crane or hoist service is not available nor practical. A strongly built, well-balanced unit with jib-arm swinging on roller bearings, this crane is built in capacities up to 5 tons, heights up to 20 feet and to a maximum radius of 20 feet. The crane is furnished with either the standard P&H pendant rope or push-button controls on the hoist or may be equipped with the new push-button master variable speed controller which controls all operations.

Circuit Breaker Relay.—This new type B relay, with magnetic release, is a product of G-M Laboratories, Chicago. It is usable as an overload cutout, a manual reset annunciator drop, and anoff-level indicator, in conjunction with a pendulum bob. It is intended for low voltage service up to 24 volts. The three contact stack mounting positions permit three operating switches at a single level. Where necessary, additional contact combinations can be added to any one of the three stacks. It can be used in multiple assemblies with a common reset arm.

Vari-Pitch Speed Changer.—This totally enclosed unit, announced by the Texrope Division of the Allis-Chalmers Mfg. Co., Milwaukee, Wis., is designed with double shaft extensions and driven from a standard motor providing the flexibility that makes

it adaptable to a wide variety of layouts to suit the individual application. It utilizes the well-known principle of the company's multi-groove vari-pitch sheaves. Where the change in speed is to be adjusted manually only, the unit is provided with a readily accessible handwheel control. It can be equipped for electric remote control, and manual remote control is also possible. The present range of capacities includes ratings up to 33 hp with ratios as high as 3 3/4 to 1. The exhibition unit illustrated is being shown at the principal national trade expositions. Descriptive bulletin 1266 is available. *Continued on page 12*

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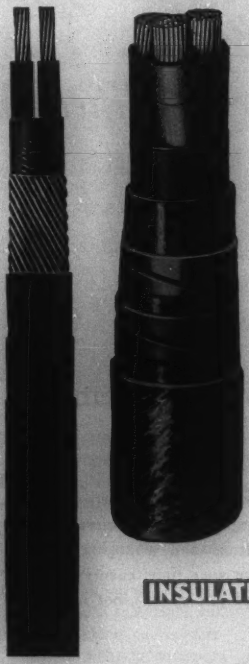

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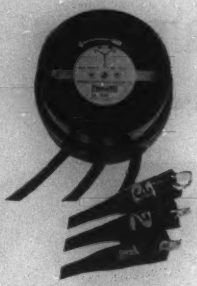

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New AIEE Standards

THE following standards are those most recently added to the AIEE series. These standards represent the recent work of Institute committees or of Sectional Committees. All but No. 19 have been approved by the American Standards Association.

No. 11 Railway Motors and Other Rotating Electrical Machinery for Rail Cars and Locomotives. An extensive revision. Approved 1936. Price 50 cents.

No. 19 Oil Circuit Breakers. Approved 1938. Price 40 cents.

No. C8.5, C8.6, C8.7 Respectively, Cotton Covered, Silk Covered, and Enameled Round Magnet Wire. An extensive revision, approved April 1936. (Supersedes Nos. 69, 70 and 71.) Issued in one pamphlet. Price 30 cents.

No. C8.11 Code Rubber Insulation for Wire and Cable for General Purposes. Approved 1936. Price 20 cents.

No. C8.12 Cotton Braid for Insulated Wire and Cable for General Purposes. Approved June 1935. Price 20 cents.

No. C8.16 Tree Wire Coverings. Approved April 1936. Price 20 cents.

No. C8.17 Class OA 30 Per Cent Rubber Insulation for Wire and Cable for General Purposes. Approved June 1936. Price 20 cents.

No. C8.18 Weather Resistant Wire and Cable URC Type. Approved December 1936. Price 20 cents.

No. C37.1 (23) Relays Associated with Power Switchgear. Approved 1937. Price 40 cents.

No. C37.2 (26) Automatic Stations. Approved 1937. Price 40 cents.

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New Products

Continued from page 8

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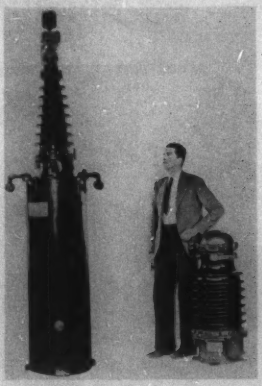

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Battery Charger.—The new Raytheon RectiChargeR, developed by the Raytheon Manufacturing Co., 149 Willow St., Waltham, Mass., changes the charging rate in

accordance with the needs of the battery. Conversion of alternating to direct current is accomplished by copper dioxide rectifying units. The control unit is a transformer product. RectiChargeRs are made for all popular battery voltages in sizes required for usual applications. An illustrated bulletin is available.

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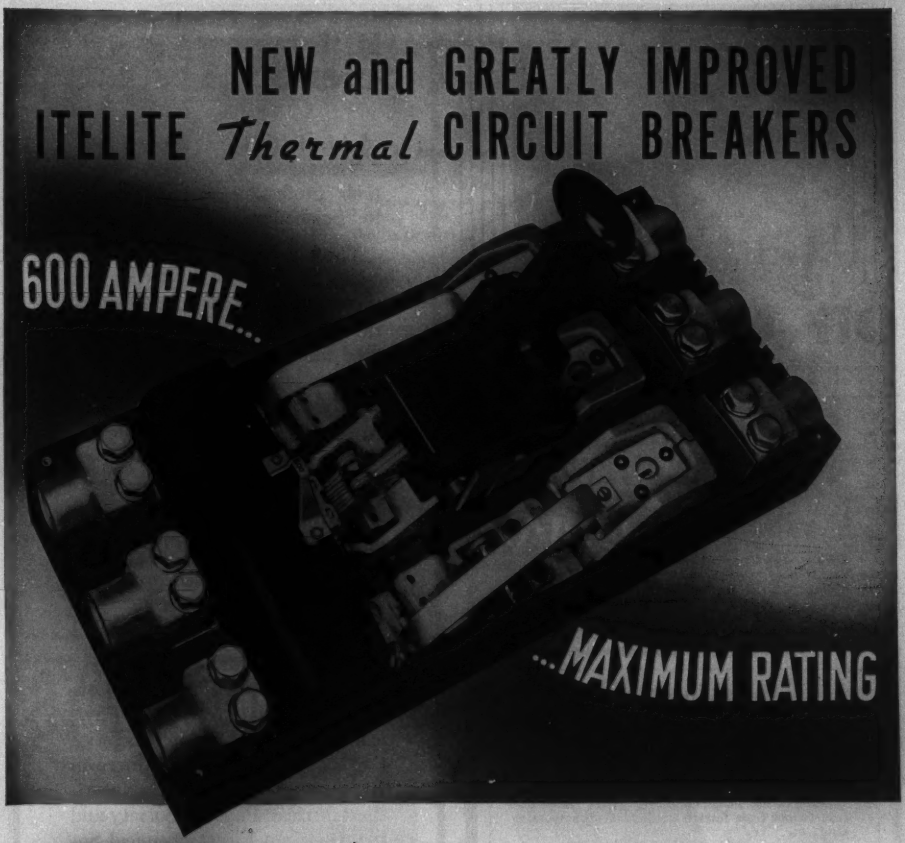

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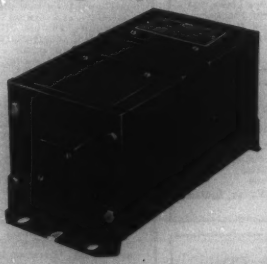

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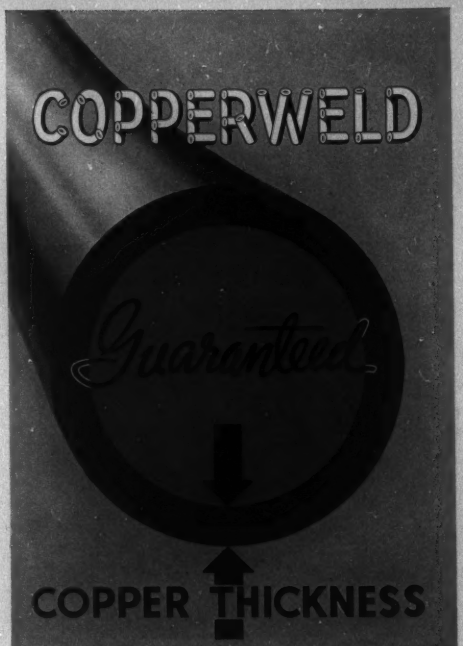

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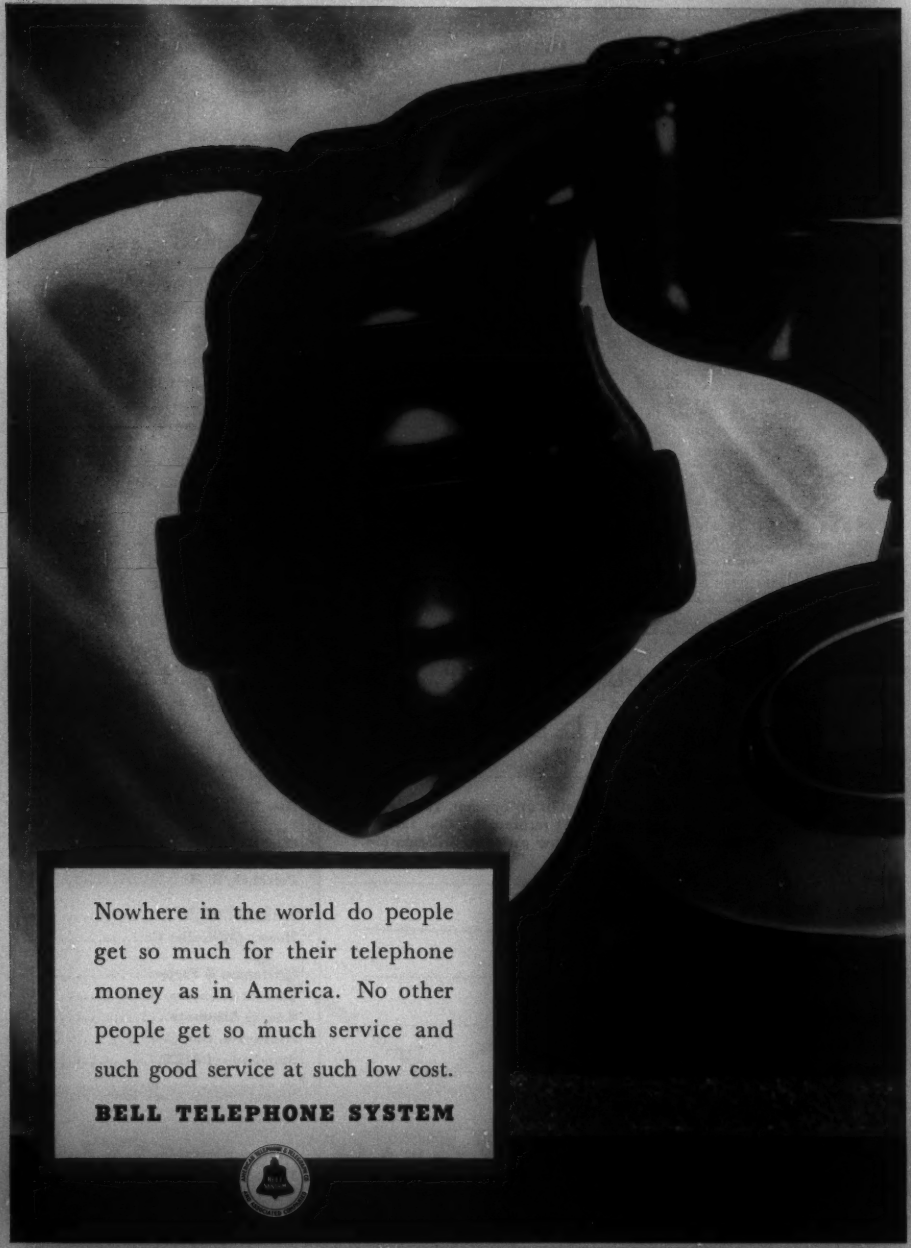
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

WIRES AND CABLES
Aluminum
Aluminum Co. of America, Pittsburgh
Armored Cable
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Asbestos Covered
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Bare Copper
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Roebling's Sons Co., John A., Trenton, N. J.
Bronze
Copperweld Steel Co., Glassport, Pa.
Copper Covered Steel
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
Flexible Cord
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Heavy Duty Cord
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Lead Covered (Paper and Var. Cambric Ins.)
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Magnet
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.
Rubber Insulated
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Trat Wire
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Weatherproof
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

THE BIGGEST TELEPHONE VALUE FOR YOUR MONEY



Nowhere in the world do people get so much for their telephone money as in America. No other people get so much service and such good service at such low cost.

BELL TELEPHONE SYSTEM

Still Serviceable After Thirteen Years

In 1924 this chestnut pole required replacement or salvage because of ground-line decay. The Williams Pole Mount salvage method was employed. Today the pole appears sound enough for another 13-year period. Equivalent Williams Pole Mount construction now would cost from $38.00 to $40.00 for grouped jobs to about $45.00 for single poles—with some extras for freight beyond 200 miles and for transportation to relatively inaccessible pole locations.

Spreading this salvage cost over the demonstrated life gives annual maintenance cost of about $3.00 to date, reducible to about $1.50 by extending the useful life to 1950. Then the Pole Mount unit on permanent concrete base is ready to receive replacement pole at same location at cost of perhaps $5.00 plus pole and overhead changes—or the entire unit may be salvaged for use elsewhere.

Figure against the above the cost of replacement of pole otherwise required in 1924 to carry trolley feeders, telephone and light and power services with riser pipe, and question whether that replacement would last until 1950. You then have the answer as to which method is cheaper. About 7,000 successful installations in United States and Canada prove we have an economic salvage construction device and method. Used also to support new poles to meet special anchorage conditions requiring development of full strength of pole.

INVESTIGATE
Send for M.I.F. Pole Hardware Specialties Catalog featuring also—Pole Stubbing Clamps—Cable Messenger Clamps—Rural Electrification Conductor Clamps—Insulated Hangers—Tubular Pole Fittings—Crossarm Gains—Through-bolt Guy Hooks and Accessory Eye Nuts, etc.

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A.I.E.E. MEMBERSHIP

To the National Secretary, A.I.E.E.
33 West 39th Street,
New York, N. Y.

_____ Date

The following persons are, in my opinion, qualified to become members of the Institute, and I recommend that they be furnished with application blanks and other pertinent information.

_____
NAME (please print)

_____
Position and Company Address

_____

• • •

_____
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Position and Company Address

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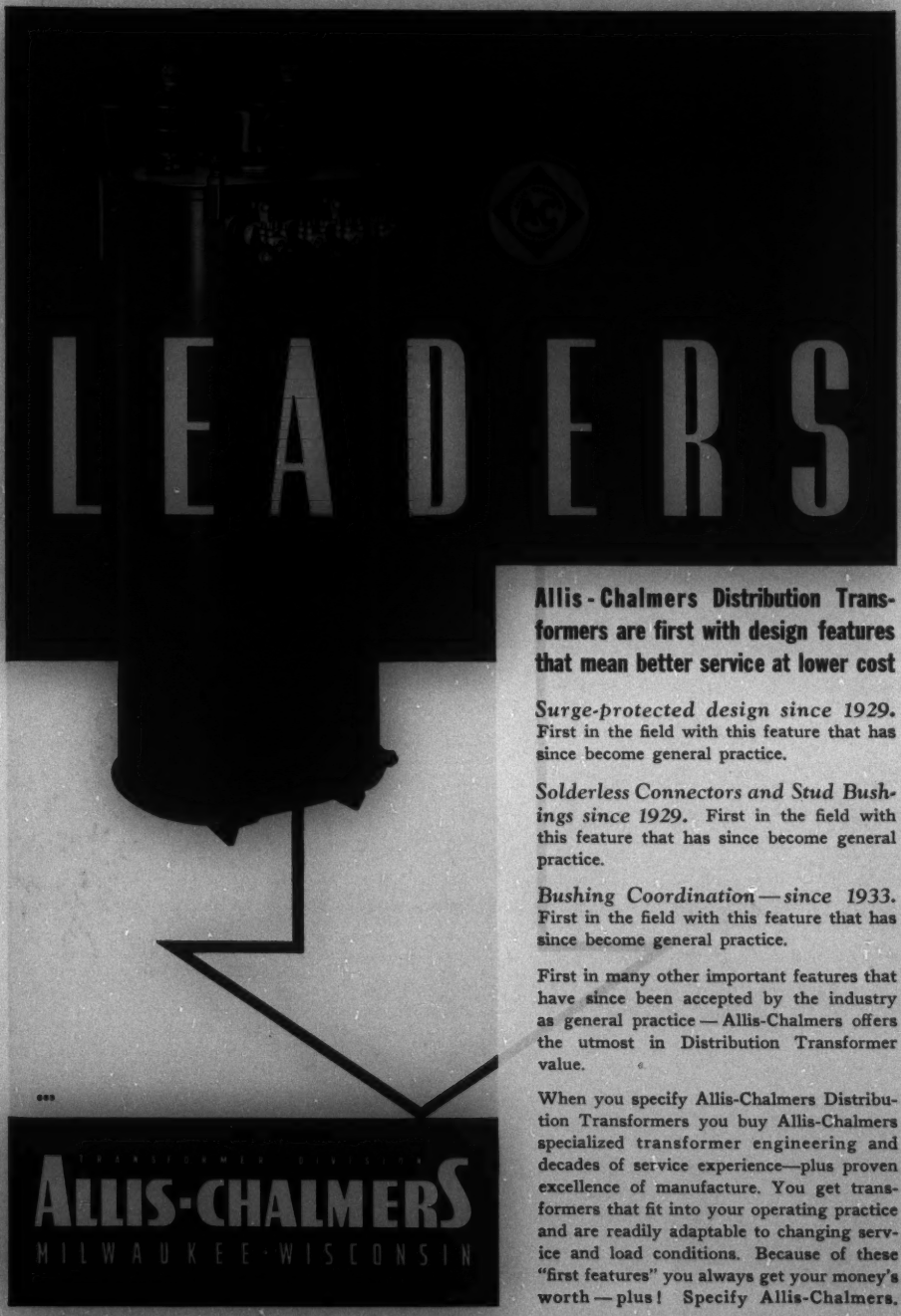

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Surge-protected design since 1929. First in the field with this feature that has since become general practice.

Solderless Connectors and Stud Bushings since 1929. First in the field with this feature that has since become general practice.

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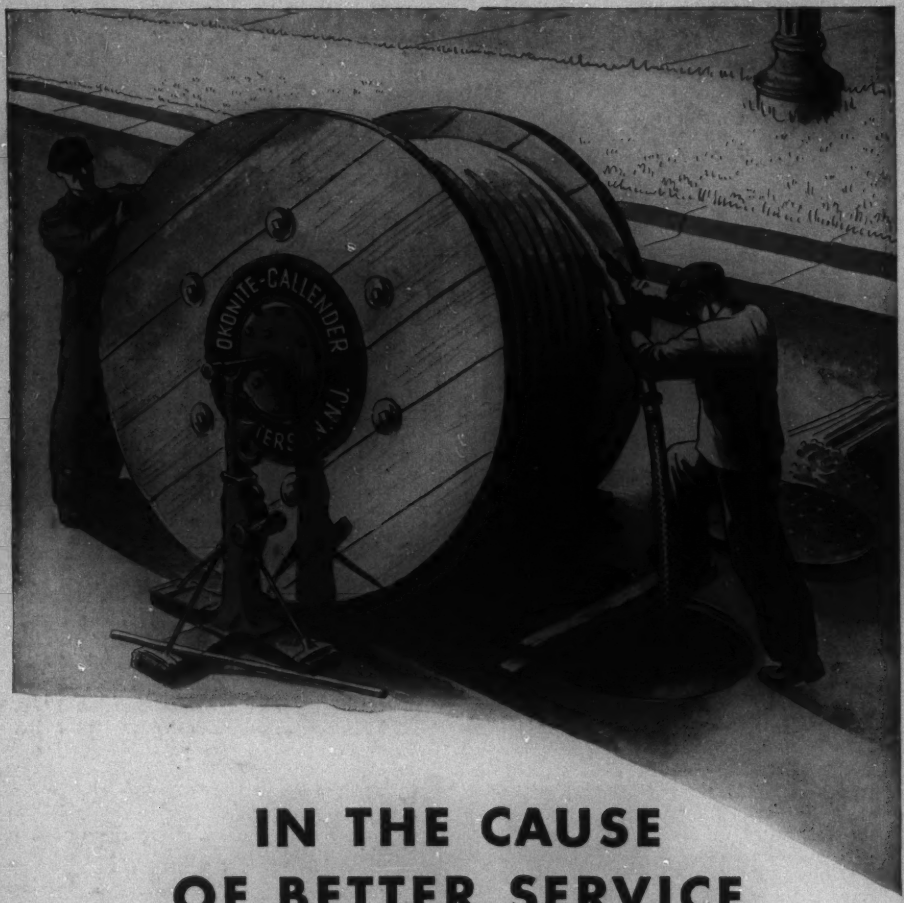

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Proper planning enables our Electric Utilities to provide their excellent service in time to meet the increasing public demand. In the same manner, the equipment manufacturers anticipate the demands of every part of the plant. This is accomplished by constant laboratory research and development of production equipment. Okonite-Callender is always ready with the right kind of cable to meet new service demands. Its facilities, too, are constantly functioning in the cause of Better Service.

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